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COMPRESSED-AIR ILLNESS AND ITS ENGINEERING IMPORTANCE

WITH A REPORT OF CASES AT THE EAST RIVER TUNNELS

BY

EDWARD LEVY

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PREFACE.

The Bureau of Mines, under the act establishing it, is charged, among other things, with investigations of the health and safety of miners. From time to time mining engineers of the bureau have been asked to give advice concerning the safety of tunnels under construction by municipalities for water supply, for sewage, and for transportation, both railway and vehicular. These problems have involved questions of ventilation for removing inflammable and deleterious gases.

In certain operations, as, for example, in the construction of tunnels in water-bearing ground and quicksands or below water level, as at Milwaukee and Cleveland, the problem of ventilation has been complicated by air pressure and the necessity of employing airlocks. Similar problems have been encountered from time to time in various parts of the country in sinking mine shafts through quicksands.

Crews of the bureau's mine rescue cars have, moreover, been called on to perform rescue and recovery operations after explosions of inflammable gas in tunnels and shafts built for other purposes than the extraction of minerals. A notable example of these operations was the recovery work at the Cleveland water-supply tunnel under Lake Erie in 1916. In this disaster 20 were killed and 13 injured by an explosion of natural gas issuing through the clays and sands of the lake bed, that part of the tunnel behind the airlock being wrecked by the explosion.

More recently the bureau, in cooperation with the New York State Bridge and Tunnel Commission and the New Jersey Interstate Bridge and Tunnel Commission, has been making investigations enabling engineers to design the ventilating system of the important pair of vehicular tunnels that are to be built under the Hudson River. The investigations involved conducting an important series of tests to ascertain the amount of poisonous and deleterious gases given off by motor trucks and automobiles under intense concentration of traffic. They also involved another series of original tests to determine the limiting proportions of these gases, in percentages of the atmosphere, that persons traversing the tunnel could safely breathe over a long period. Determination of questions that involve the health of users of the tunnel was fundamental to the whole design of this important undertaking.

Similar physiological questions have arisen in designing the ventilating systems of other tunnels, such as the twin vehicular tunnels

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now under construction at Pittsburgh. The problem of vehicular tunnel ventilation is allied to that of regulating the use of gasoline locomotives in mines.

Dr. Levy's paper is one of the series dealing with the physiological problems arising in mining and underground engineering developments and relates specifically to methods of overcoming the ill effects on men of increased atmospheric pressure which was detrimental to the health of the workers under earlier working conditions. At one time these hazards were regarded as inherent in the occupation of shaft sinking and tunneling under the high air pressures necessary to keep back the water in wet ground and quicksand as in the sinking of caissons for the Eads Bridge piers at St. Louis where serious loss of life resulted from caisson disease.

The fundamental work of Dr. J. S. Haldane, the noted British physiologist, and of other physiologists on deep-sea diving conditions gradually led to improvement in preventive measures. During the tunnel work in and about New York the methods became systematized and so improved as almost to eliminate severe or fatal cases, as indicated in the text of this paper.

Some persons may think that this class of work is largely limited to New York, but that is not so. Compressed-air methods have to be used in many parts of the country in foundation construction, in tunnels for various purposes, and in mine shafts to penetrate glacial deposits or water-filled silt or sand to reach underlying minerals.

It has been apparent to the mining engineers of the bureau that the rest of the country has learned little of the successful methods developed in New York, and the health of workers has been injured and loss of life has occurred in underground engineering enterprises elsewhere.

It was decided that the matter was of national importance, and accordingly arrangements were made with Dr. Levy for the preparation of this paper as one of the physiological mining-engineering studies undertaken by the Bureau of Mines in cooperation with the U. S. Public Health Service.

George S. Rice.

COMPRESSED-AIR ILLNESS AND ITS ENGINEERING IMPORTANCE; WITH A REPORT OF CASES AT THE EAST RIVER TUNNELS.

By EDWARD LEVY.[1]

INTRODUCTION.

Compressed-air work has assumed a place of enormous economic importance in modern engineering. Frequently deep-mining operations, subaqueous tunneling, and bridge building can be conducted only by the aid of compressed air. The construction of underwater tunnels or "tubes," the principal means of intercommunication between such large business centers as Manhattan Island and Brooklyn, would be impossible without it. The prosecution of these various activities requires the employment of numbers of men who must work under varying degrees of air pressure. The effect of compressed air upon the life, health, and efficiency of workers becomes, therefore, of increasing importance in the study of occupational diseases and the medical problems of industries. In view of its importance to the physician and the engineer, the subject merits much more extensive research than in the past.

This report is based on the writer's experience as physician to the Public Service Commission for the First District, State of New York, which supervised the building of the four pairs of tunnels constructed under the East River during the years 1914 to 1919. The construction of these tunnels was the greatest engineering feat of its kind ever undertaken.

Dr. Keays' report, published in 1909, on the work under compressed air in the Pennsylvania R. R. East River tunnel from 1904 to 1909, described an improved system of handling employees and tabulating records, and gave data showing great reduction in compressed-air illness. In consequence of the knowledge gained from a study of improved methods, from results of previous undertakings, and by making such changes from time to time as experience seemed to warrant, the work under the control of the Public Service Commission shows a decided decrease in the proportion of compressed-air illness. The fact remains, however, that no thorough research has been done in this field in the United States. Knowledge of the cause, character, and treatment of compressed-air illness is still limited to a very few physicians, and thus far little interest in the subject has been evinced by the medical profession at large.

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[1] Consulting physiologist, Bureau of Mines; consulting physician, New York State Bridge and Tunnel Commission and New Jersey Interstate Bridge and Tunnel Commission; and physician, Transit Commission, New York City.

ACKNOWLEDGMENTS.

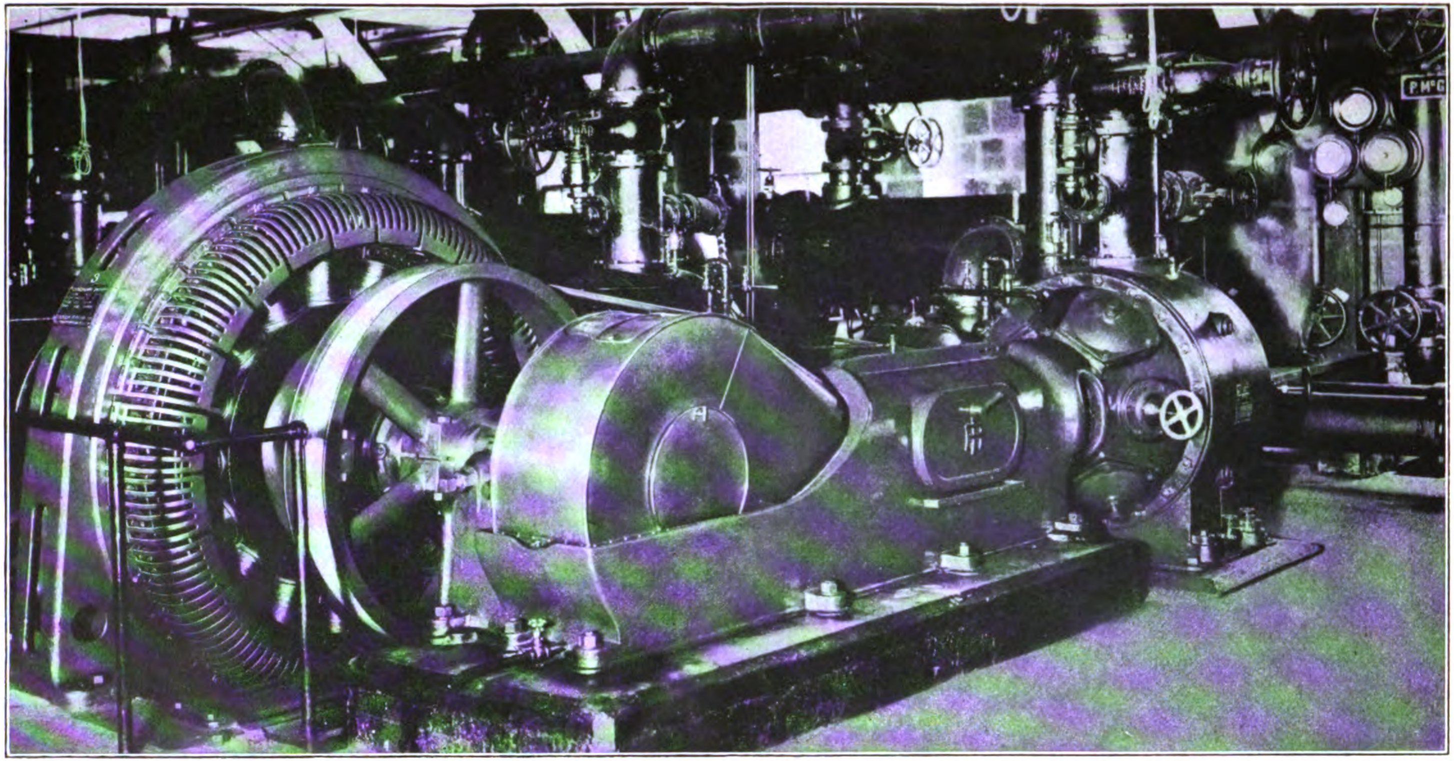
Acknowledgment is made to the engineers of the Transit Commission and to Mr. Clifford M. Holland, chief engineer to the New York State Bridge and Tunnel Commission and New Jersey Interstate Bridge and Tunnel Commission, for many courtesies and valuable assistance rendered; to the contractors' physicians for their cooperation; and to Mr. Sydney Rosmarin, who kept the author's records and charted the results.

MECHANICAL APPARATUS USED IN DRIVING TUNNELS WITH COMPRESSED AIR.

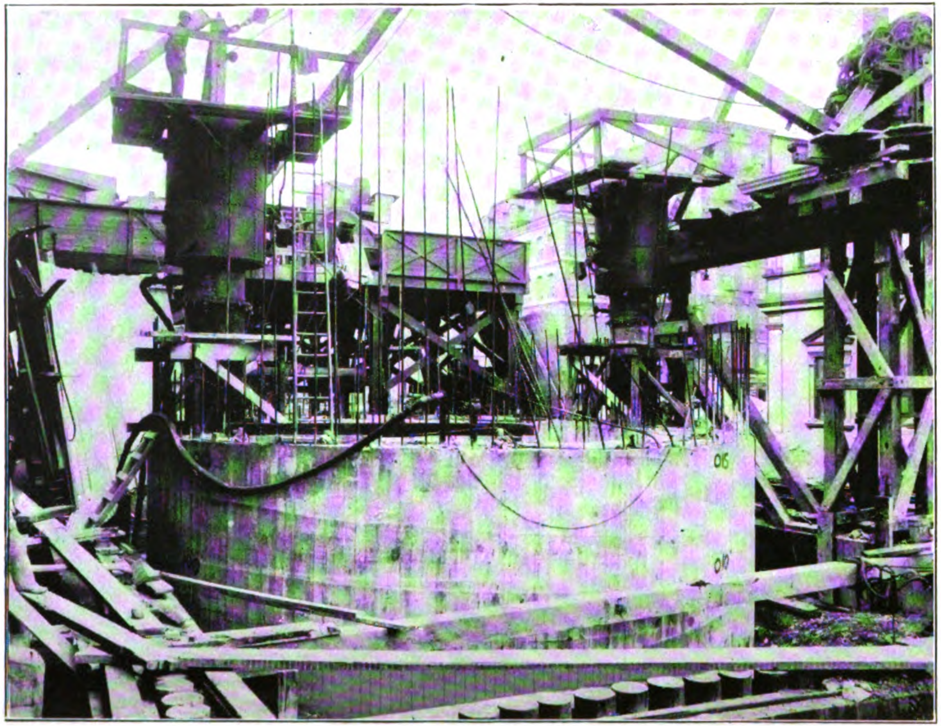
The construction of a subaqueous shield-driven tunnel by the compressed-air method requires, before tunneling operations are begun, first, the erection of an air-compressing plant and, second, the sinking of the shafts from which the tunnels are to be driven.

The air delivered into the tunnel headings is compressed by electric or steam-driven air compressors set in buildings near the tunnel shafts. The intake pipe to the compressors is on the outside of the power house and is screened to keep out all foreign matter, insuring a supply of air free from smoke and dust. Through this pipe air is drawn into the air compressors and compressed. From the compressors the air passes into a large tank called a receiver, where the compressed air is freed from lubricating oil and the pressure in the air line is equalized. During compression the air becomes heated to a temperature that would make working conditions intolerable; consequently, it goes from the receiver to a cooler through which water is circulated and the temperature of the air is reduced. The air then goes through suitable piping down the shaft and through the tunnel bulkheads into the working chambers. To insure an uninterrupted supply, all air lines are in duplicate and are provided with back-pressure valves, so that if the pressure in the air line should become less than that in the chamber the air could not escape back through the pipes.

The capacity of an air-compressing plant is determined by the conditions under which the work is to be done, such as the diameter of the tunnel, the character of the material through which the tunnel is being driven, and the depth of the tunnel below water surface. The largest air-compressing plant used for any of the East River tunnels had a capacity of 45,000 cubic feet of free air per minute at a pressure of 45 pounds per square inch. This means that the piston



PUBLIC SERVICE COMMISSION CONTRACTOR'S POWER PLANT, AIR COMPRESSOR IN FOREGROUND.



ARRANGEMENT OF AIR LOCKS ON A CIRCULAR, REINFORCED CONCRETE CAISSON.

displacement of all the machines was 45,000 cubic feet every minute and that the power used was capable of compressing air from atmospheric pressure to a pressure of 45 pounds per square inch. The eight machines in this plant had an individual capacity of 5,700 cubic feet per minute. (See Pl. I.) As the air pressure in the tunnel fluctuated, the output of the plant was varied by automatic devices which cut down the air supply in accordance with the demand. Each man working in compressed air in the New York tunnels received over 4,000 cubic feet of fresh air per hour.

The shafts are sunk through water-bearing earth by caissons built upon the surface of the ground and sunk to the subgrade of the tunnel by excavating at the bottom of the shaft in an air-tight room known as the working chamber. As excavation proceeds, the shaft or caisson sinks to its final position. Then the bottom is sealed with concrete and the work of tunnel driving can begin.

Plate II shows a caisson of the circular type, and Plate III a caisson of the rectangular type. Both plates are photographs of the part that appears above ground.

Plates IV and V show two stages of operatings in the working chamber of the rectangular caisson, Plate IV showing the excavation of soft muck, and Plate V the working chamber excavated but far from dry. (Pages 11 and 14.)

In tunneling through a subaqueous material the shield with compressed air is used almost universally. After the shield has been assembled at the bottom of the shaft it is moved out through the side of the shaft by hydraulic jacks. As the shield advances the tunnel lining is erected directly behind it under the protection of the "tail" which overlaps the complete structure. Tunneling is carried on continuously until the shield meets a second shield driven in like manner to the meeting point, or until it enters another shaft similar to the one described.

Plate VI shows the mouth of a tunnel from a caisson. (Page 15.)

Plate VII is a photograph of a shield from the tunnel after it has been pushed forward by hydraulic jacks, leaving room for another iron ring to be placed. (Page 16.)

Plate VIII shows a shield which has entered a rock after having been pushed through soft material. At this point the shield's usefulness comes to an end. (Page 17.)

Plate IX shows a section of the tunnel half flooded. In order to shut off certain valves, it was necessary to send in a diver, who is seen working in his own supply of compressed air in the compressed air of the tunnel. (Page 18.)

Plate X gives a general view of the tunnel, especially the exit for cars containing muck, the man lock, and the emergency lock. (Page 19.)

Plate XI shows air "blowing" to the surface of the river from the face of the tunnel before the bed of the river was reinforced with clay. (Page 20.)

CAISSON DISEASE.

Caisson disease, compressed-air illness, or, more properly speaking, air embolism, is a condition caused by a too rapid decompression after exposure to higher pressures for a period of time. It is characterized anatomically by the presence of free nitrogen in the tissues and body fluids and clinically by one, or a combination of the following symptoms: Localized pain, vertigo, prostration, or symptoms referable to the central nervous system.

ETIOLOGY.

Many theories have been advanced as to the cause of compressed-air illness, but it is now universally agreed that the presence of free nitrogen in the various parts of the body, interfering with their normal functions, is the true cause. The exact method of the formation of these bubbles and their subsequent lodgment will be discussed under the heading "Nitrogen."

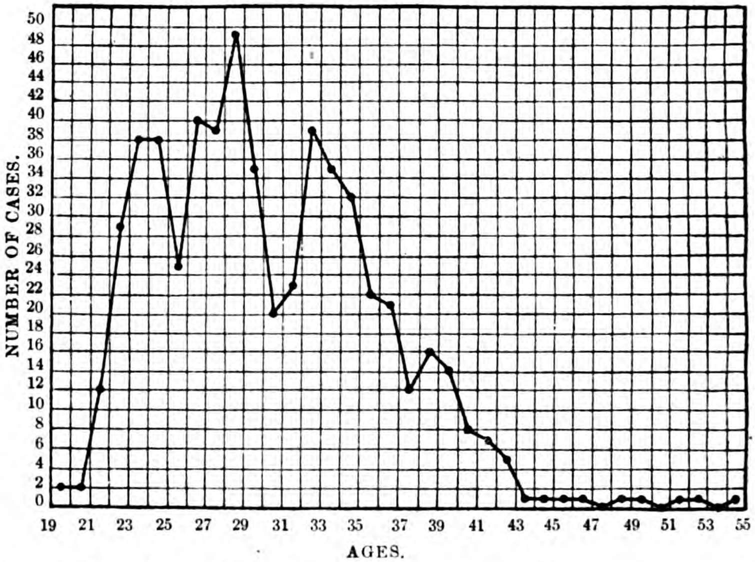
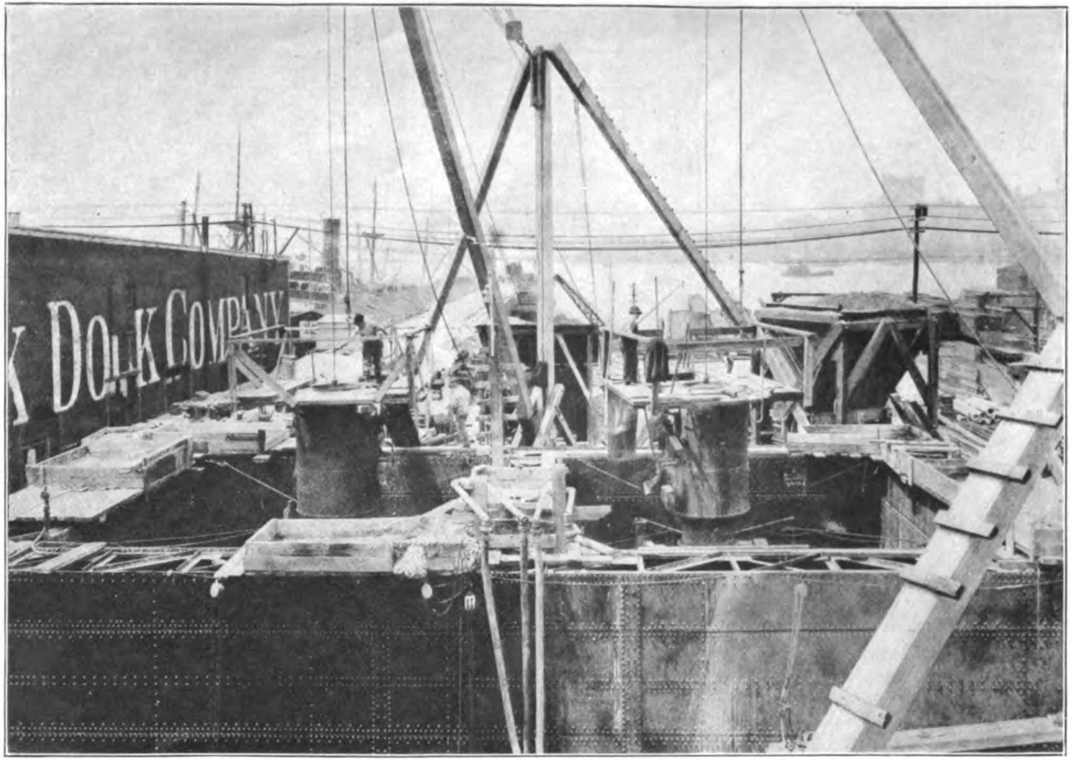


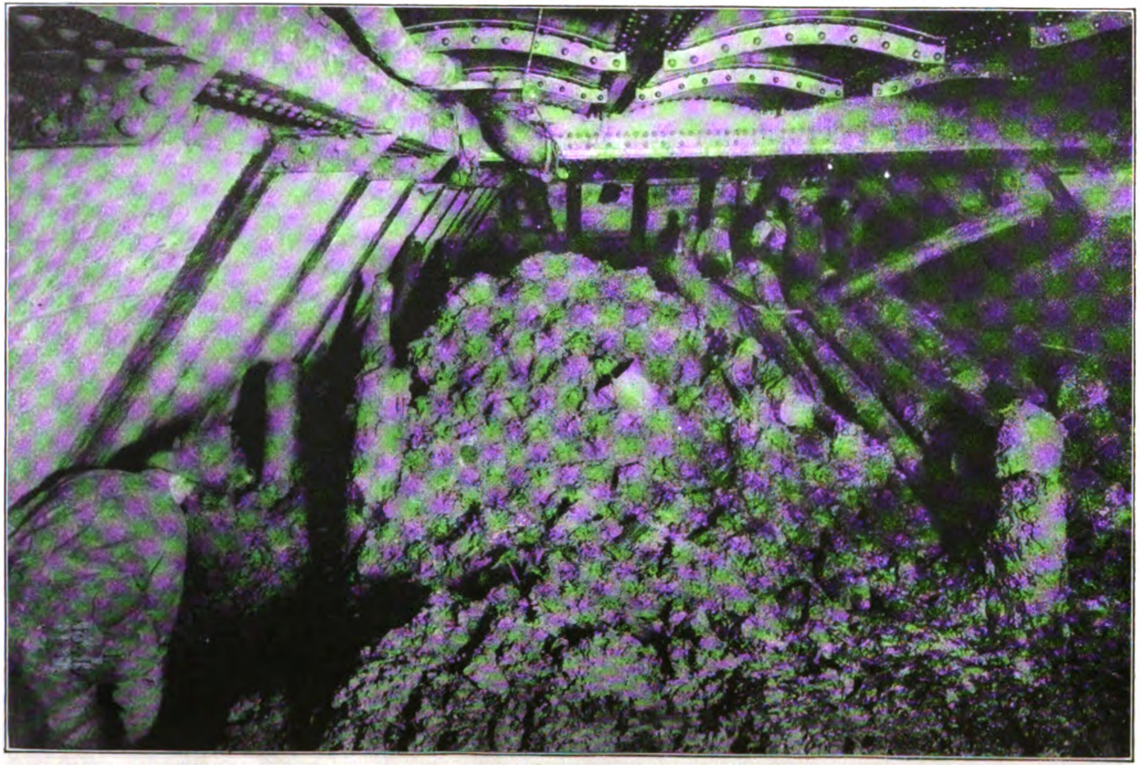
FIGURE 1.—Ages of men who had compressed-air illness. The age was not reported in 108 cases.

SELECTION OF MEN.

In an employment so hazardous as that of a "sand hog" some attention should be paid to the class of men best fitted for it. Per-



ARRANGEMENT OF AIR LOCKS ON A RECTANGULAR STEEL CAISSON.



PILES AND CRIBBING ENCOUNTERED IN INTERIOR OF WORKING CHAMBER OF A RECTANGULAR STEEL CAISSON; WORKMEN EXCAVATING SOFT MUCK.

haps too much has been said in favor of thin men, young men, and athletic men generally. Originally the writer, as physician of the Public Service Commission for the First District, State of New York, rejected many men whom he did not consider physically perfect; but as the majority of men of sturdy physique were in the service during the war, the commission was forced to employ men that were very mediocre physically. Actual experience has led to the conclusion that in the selection of men the essentials are normal lungs, normal kidneys, and a good heart; in the older men the blood pressure must not be high.

AGES.

Unfortunately it was impossible to ascertain with accuracy the ages of all men who worked in compressed air in the recently completed East River tunnel, but it is known that very few were under 20 years of age; 87 men were over 50, and one was over 60. The older men find it necessary to give fictitious ages in order to obtain work; for this reason the records regarding ages can not be relied on. However, the source of the information in relation to the 87 men is beyond question, although not a matter of record. Figure 1 shows that the greatest number of the cases of compressed-air illness occurred in men 28 years of age; the next greatest in those of 26 years; and then in those of 27 and 32 years. As a number of workers of each age is not known, no chart showing the percentages of cases at the various ages can be constructed. The records do show, however, that among the 87 men over the age of 50 there were only three cases of compressed-air illness. This would indicate that in selected men advanced age may not be such an important factor as many writers insist. Further research and more extended observation on this point are needed before any decisive conclusion can be drawn.

OBESITY.

In reference to the employment of fleshy men, that is, men with a moderately increased amount

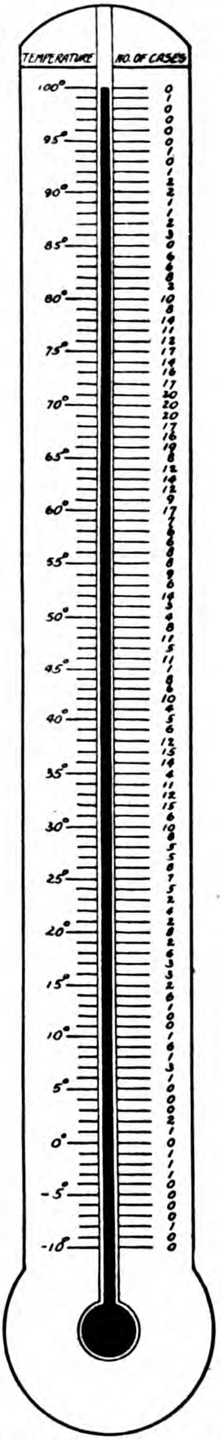


FIGURE 2.—Temperatures in which cases of compressed-air illness occurred.

of adipose tissue, the writer's experience has been that such men are not more susceptible to compressed-air illness than is the average individual. The writer does not recommend that corpulent men be permitted to work in compressed air, but he is less inclined than are some others to enforce strictly a rule that no man with a tendency to fatness be employed.

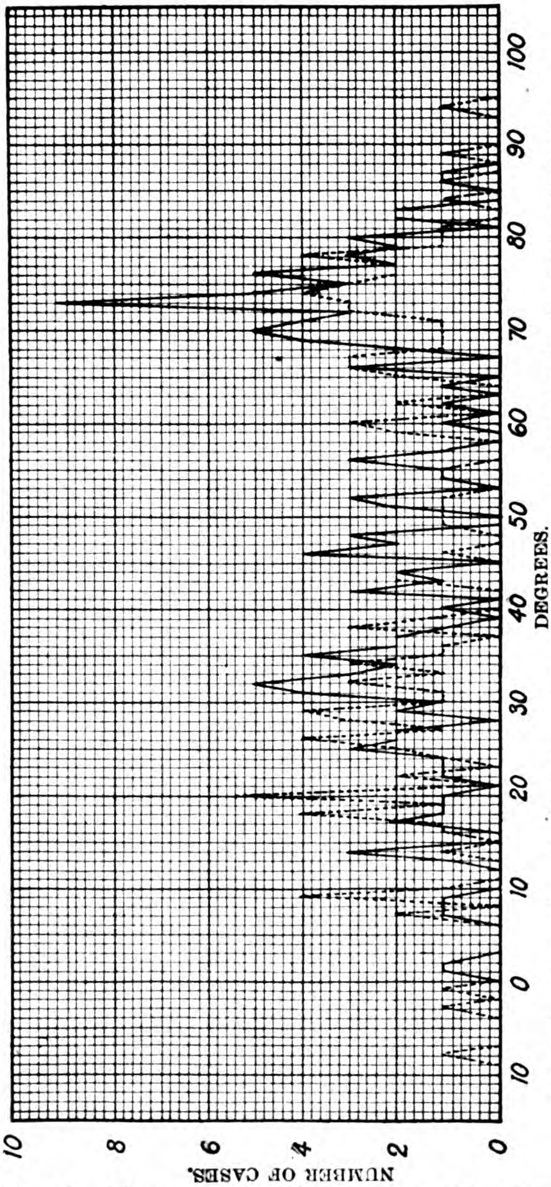


FIGURE 3.—Temperatures in which cases of compresser-air illness occurred under 29 and 34 pounds pressure. ———, 29 lbs. pressure; - - - - - - - -, 34 lbs. pressure.

TEMPERATURE.

The external temperature in New York City during the four years in which the work of the Public Service Commission was in progress ranged from —13° to 102° F. The records indicate that temperature has little, if any, influence on increasing the number of cases of compressed-air illness (see figs. 2 and 3). Figure 3 shows the number of cases that occurred in each degree of temperature while the men were working under 29 and 34 pounds pressure, the greatest number being at 73° F. Moreover, humidity does not seem to cause any increase, although its effect is evidenced by increased fatigue. During a spell of extremely hot weather one of the locks on the shaft was exposed to the sun, causing an intense heat within the lock while the men were decompressing. The high temperature did not increase the number of cases of compressed-air illness, but the men suffered from exhaustion after they left the lock. An electric fan was also installed in the lock to keep the air in circulation. This relief from the heat was appreciated by some of the men, but as a few were afraid of being chilled its use was discontinued.

As has been stated, the external temperature made no difference in the number of cases of compressed-air illness, but this was probably because the range of temperature in the working chamber varied little, regardess of whether zero weather or hot weather prevailed outside. In the working chamber the temperature was always about 77° F., whereas the annual report of the Weather Bureau[1a] showed that in New York City "the excessive heat wave beginning July 30 and ending August 2, 1917, caused over 200 deaths and 2,000 prostrations, as reported by the press."

HOURS OF LABOR AND PRESSURES IN WORKING CHAMBER.

The records indicate that the number of cases of compressed-air illness depends upon the length of time the subject has been in pressure, the height of the pressure, and the length of time taken for decompression.

ATMOSPHERIC TO 22-POUNDS GAGE.

In analyzing the hours of labor, the period from atmospheric to 22-pounds pressure gage, when men work eight hours with a half hour in which to return to normal air for lunch, will first be considered. No case of compressed-air illness occured until the pressure of 15 pounds was reached, although the number of decompressions by that time had reached 188,496. The number of cases that resulted from working in pressures of 15 to 22 pounds was as follows:

Cases of compressed-air illness from pressures ranging up to 22 pounds per square inch.

Pressures, pounds.	Number of cases.	Number of decompressions.
15	1	73, 956
16	1	17, 625
17	1	93, 333
18	2	45, 256
19	4	66, 997
20	4	70, 605
21	3	65, 074

Sixteen cases in all occurred from 621,342 decompressions. As all of these cases were trivial, it appears to be quite safe to subject normal, healthy men to pressures ranging up to 22 pounds for a period of eight hours.

[1a] Annual Meteorological Summary, New York, 1917.

22 TO 30 POUNDS GAGE.

In the second period—for pressures of 22 to 30 pounds—the shifts were divided into two 3-hour periods, with a rest interval of three hours. The number of cases was as follows:

Cases of compressed air illness from pressures of 22 to 30 pounds per square inch.

Pressure, pounds.	Number of cases.	Number of decompressions.
22	0	19,187
23	3	24,018
24	10	17,009
25	5	23,239
26	19	42,458
27	29	35,827
28	96	102,851
29	139	56,092

The most noticeable feature of this table is the gradual rise in number of cases with increase of pressure until the peak of compressed-air illness is reached at 29 pounds with 3-hour shifts.

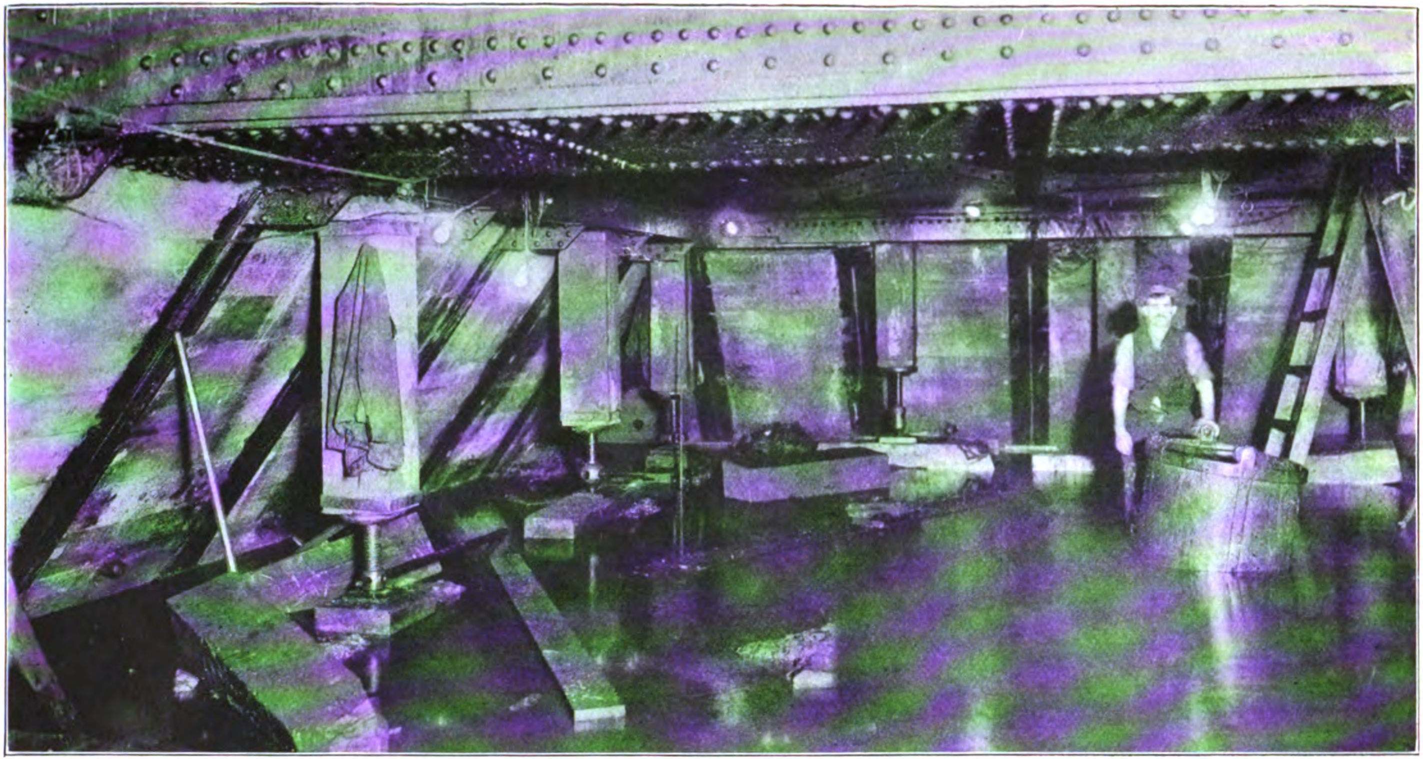
30 to 35 POUNDS GAGE.

In the next stage, with pressures ranging from 30 to 35 pounds, the shifts were divided into two 2-hour periods, with a rest interval of two hours. The record was:

Cases of compressed air illness from pressures of 30 to 35 pounds per square inch.

Pressure, pounds.	Number of cases.	Number of decompressions.
30	14	28,538
31	36	56,291
32	37	41,356
33	50	63,846
34	113	75,111

The remarkable feature of this stage is that, although the men worked in higher pressures than before, there was a marked falling off in the number of cases of compressed-air illness. At 29 pounds there were 139 cases and at 30 pounds only 14, the time of decompression being relatively the same. This decrease in the number of cases was due entirely to changing from 3 to 2 hour shifts. Figures 4 and 5 prove conclusively that the danger point of saturation is reached when men are permitted to work three hours in 29 pounds pressure. Had the length of shift been changed at 29 pounds instead of at 30 pounds, 111 cases would probably have been eliminated and the percentages of compressed-air illness would have been cut down decidedly. It is further shown that in the third stage, between 30 and 35 pounds, there was a gradual increase in the number of cases, the maximum being at 34 pounds.



INTERIOR OF WORKING CHAMBER OF RECTANGULAR STEEL CAISSON SUPPORTED ON JACKS PRIOR TO THE APPLICATION OF COMPRESSED AIR.

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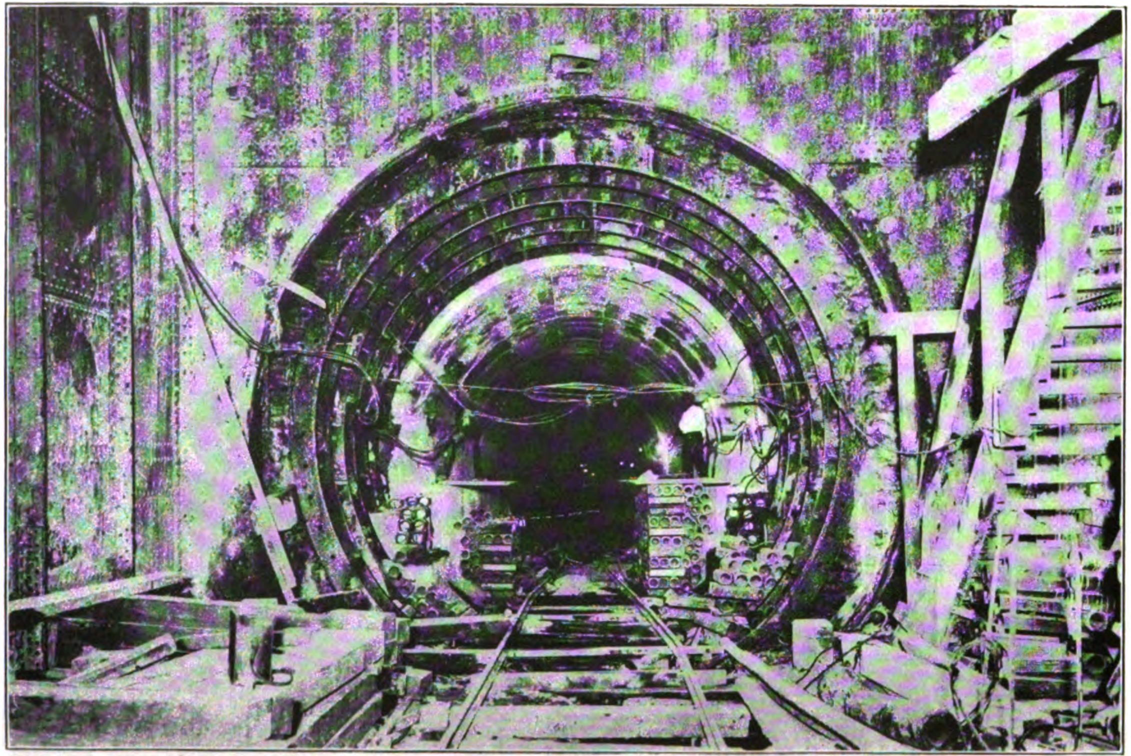
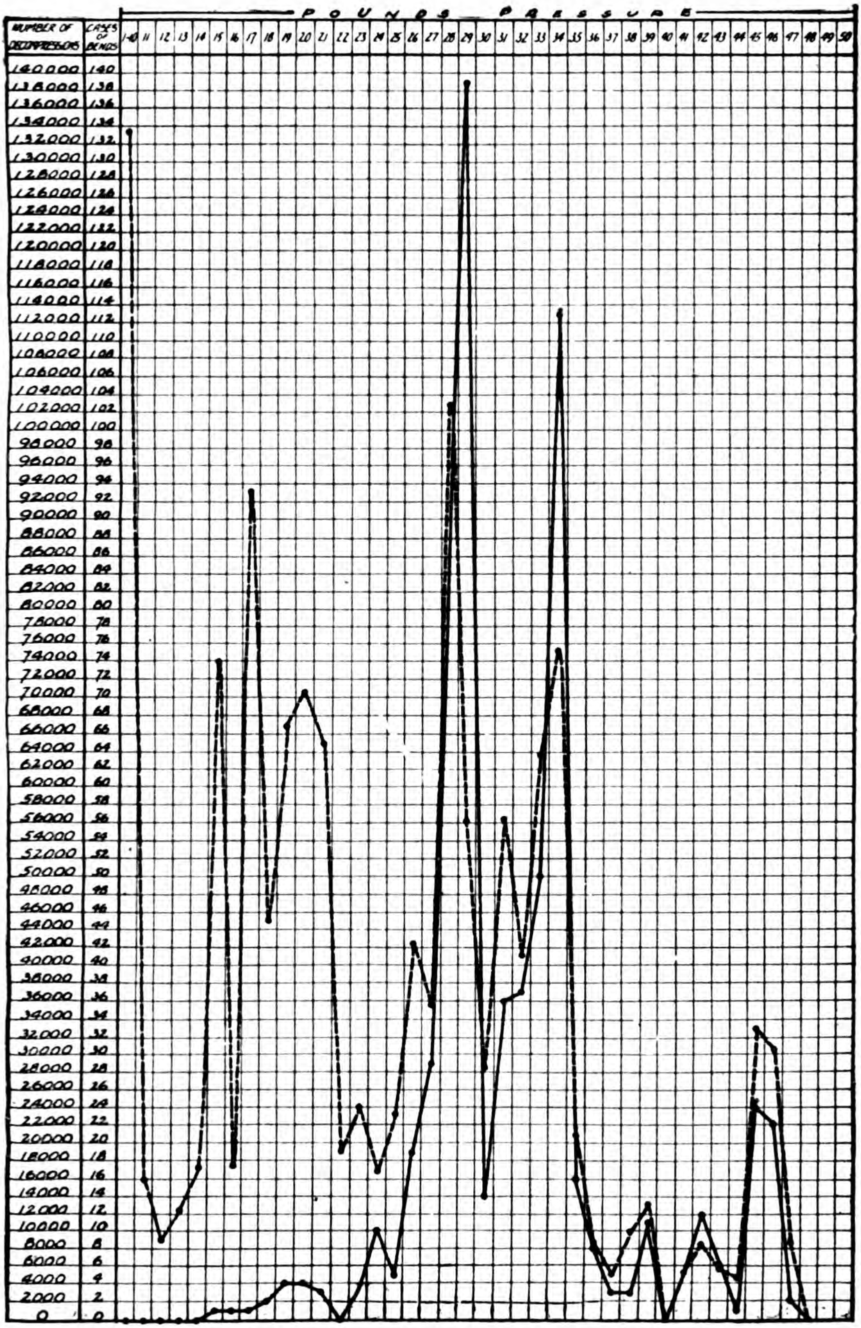


PORTAL OF CAST-IRON LINED TUNNEL FROM INSIDE OF SHAFT CAISSON; COMPLETED CONCRETE LINING IN BACKGROUND.



------ Decompressions; ——— cases of bends; * Death.

FIGURE 4.—Total decompressions and bends under various pressure in the tunnels built under the supervision of the Public Service Commission.

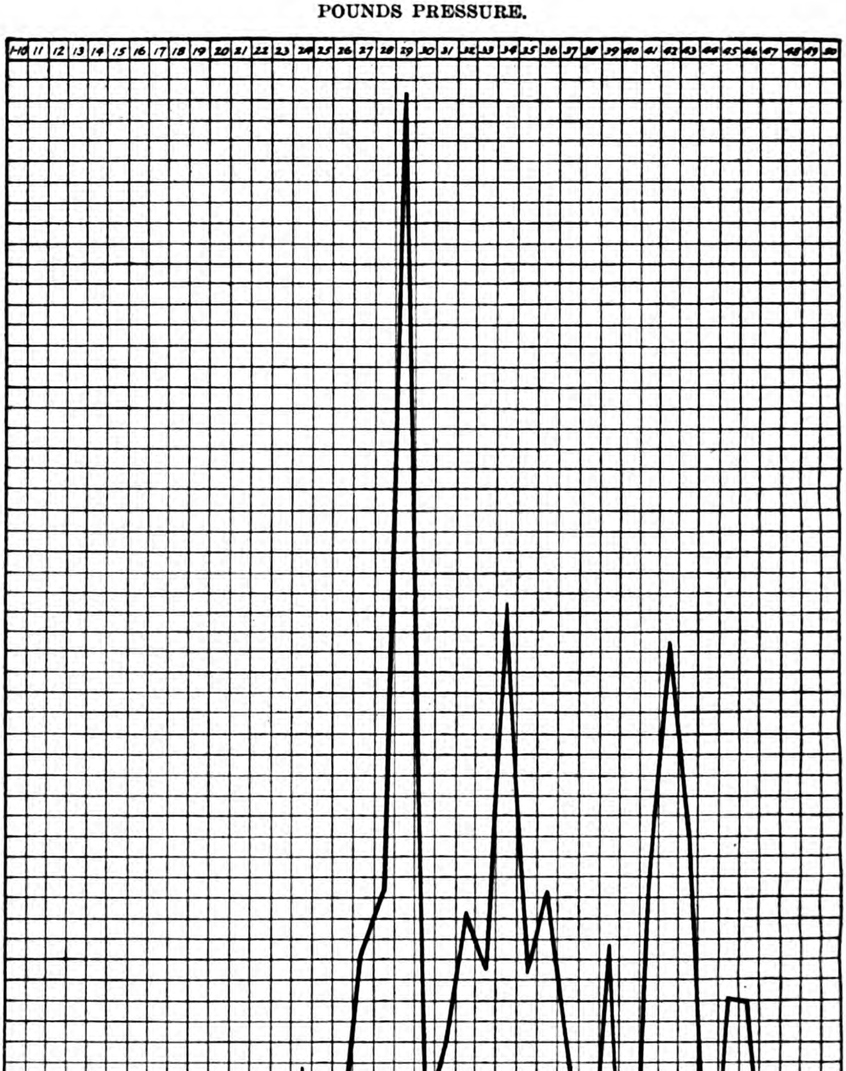
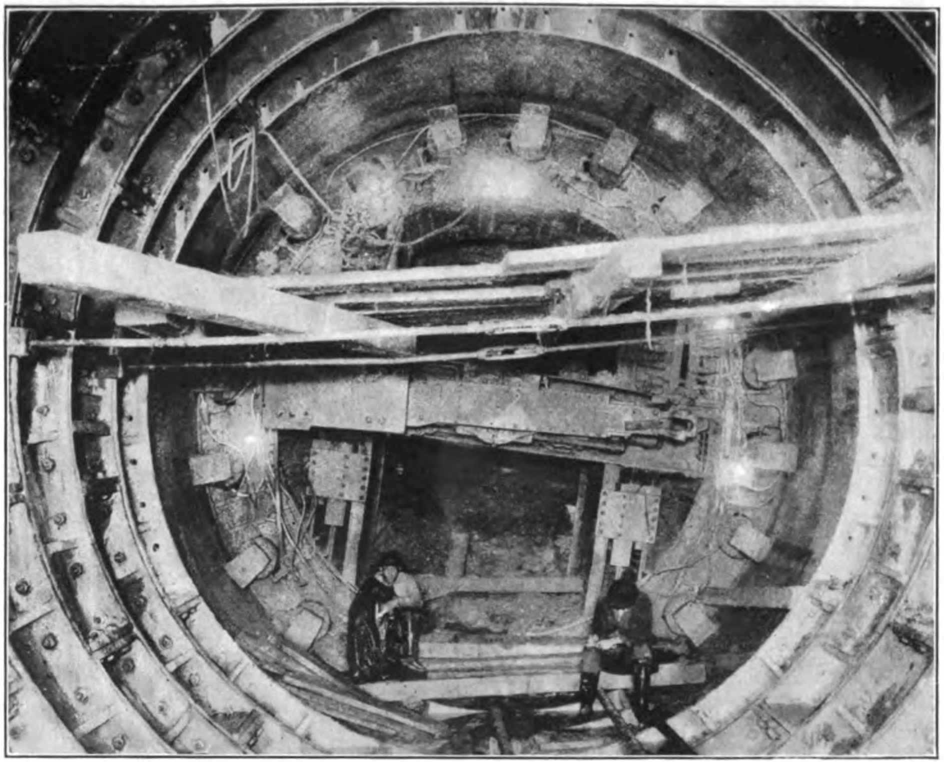
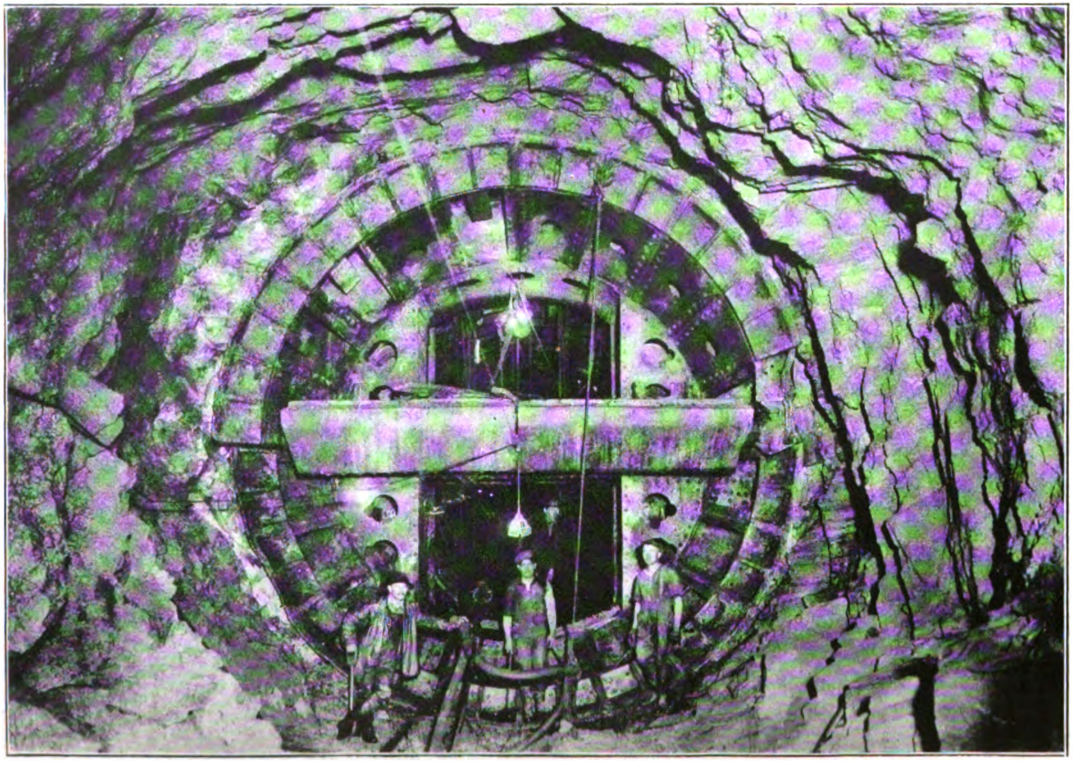


Figure 5.—Ratio of percentage of compressed-air illnesses in various pressures.



REAR VIEW OF SHIELD, AFTER COMPLETION OF A SHOVE, READY FOR THE ERECTION OF A NEW RING OF TUNNEL LINING.



FRONT VIEW OF SHIELD ENTERING ROCK.

35 TO 40 POUNDS GAGE.

In the next stage, the pressure ranged from 35 to 40 pounds and the shifts were divided into two 1½-hour periods, with a 3-hour interval for rest.

Cases of compressed-air illness from pressure of 35 to 40 pounds per square inch.

Pressures, pounds.	Number of cases.	Number of decompressions.
35	16	20,816
36	8	8,629
37	3	5,048
38	3	9,972
39	11	13,253

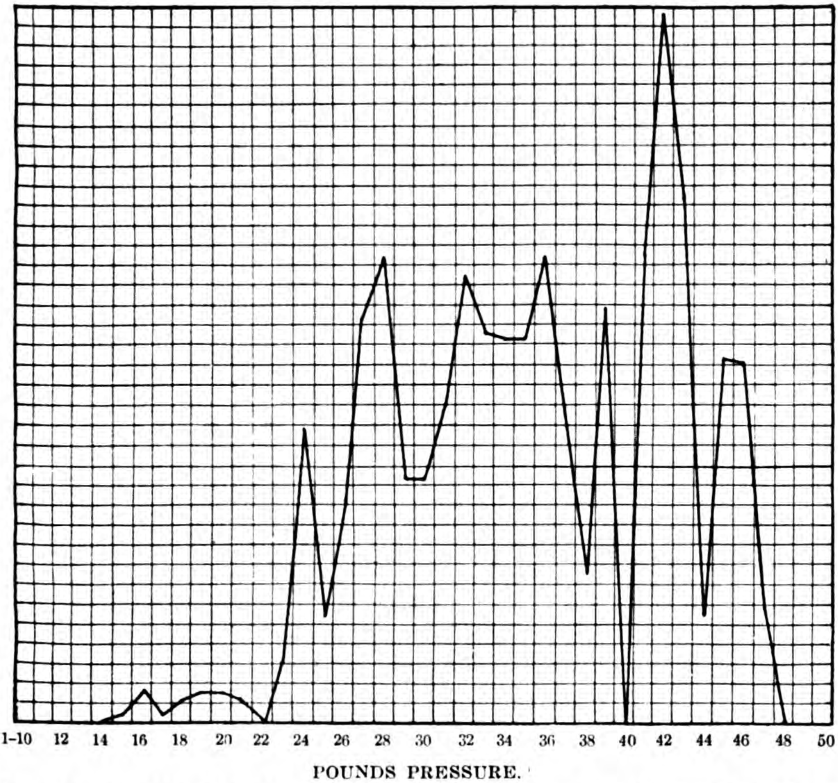


FIGURE 6.—Probable ratio of percentage of compressed-air illness if the shifts had been changed at 29 and 34 pounds, instead of 30 and 35 pounds.

The phenomenon was repeated. The number of cases that occurred at 35 pounds was less than at 34 pounds, and this again was due to changing the hours of labor. Figure 4 (p. 15) conclusively shows that working two hours in 34 pounds pressure is just a little too much, and that the change to the shorter shifts should be made at 34 instead of at 35 pounds. Fifty-five cases would probably have been

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eliminated had the length of shifts been changed at 34 instead of at 35 pounds pressure. Figure 5 (p. 16) shows the actual ratio of percentages of compressed-air illness when the hours of labor were changed at 30 and 35 pounds, whereas figure 6 indicates what the theoretic ratio would have been had the change of shifts taken place at 29 and 34 pounds.

The decompressions above 36 pounds were too few to supply any data. It is the author's belief that the problem of length of shifts for pressures up to 35 pounds has been practically solved, with due regard for safety, and that a curve of hours of labor in certain pressures could be plotted to insure almost absolute security to the men.

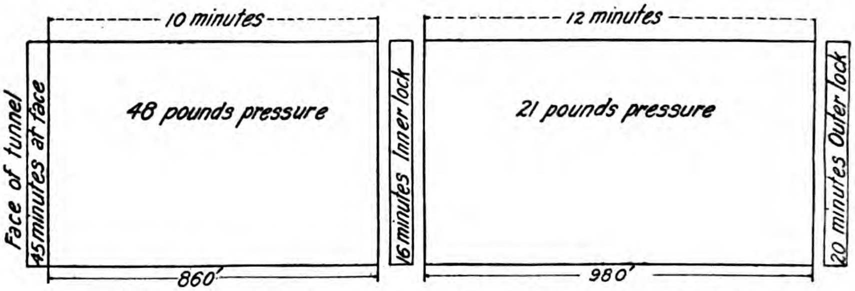


FIGURE 7.—Division of compressed-air worker's time during a shift.

TIME IN COMPRESSED AIR.

	Minutes.
Inner chamber	12
Working chamber	10
Face	45
Working chamber	10
First lock	16
First chamber	12
Outer lock	20
Total	125

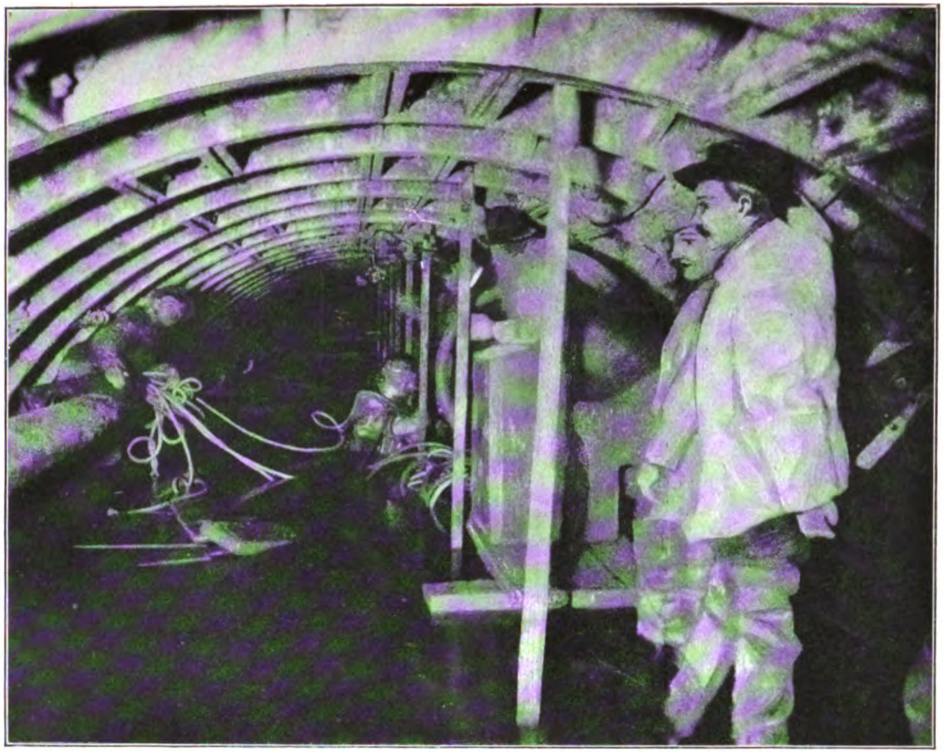
TIME FOR DECOMPRESSION.

	Minutes.
First lock	16
First chamber	12
Outer lock	20
Total	48

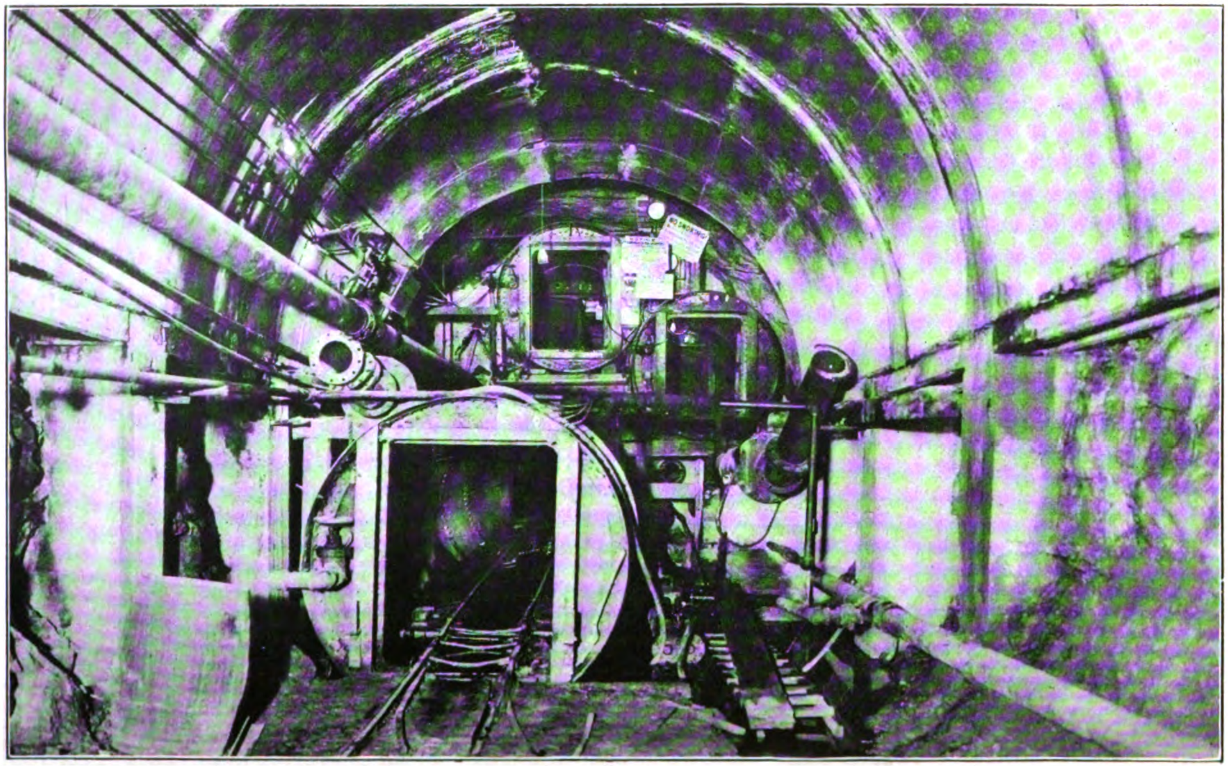
The hours of labor referred to in this report do not mean the actual time spent in compressed air, but the time spent in working at the face. Where the work is far advanced, the working face may be at the middle of the river, and much time, therefore, would be consumed in walking from the shaft. At 48 pounds, the pressure at which the men were working, the length of time actually spent in the air was 125 minutes (see fig. 7), so that, although credited with working only two shifts of 45 minutes each, or 90 minutes, a man has spent two shifts of 125 minutes each in compressed air. No accurate data can be obtained on this point until "hours of labor" means entrance and exit from compressed air.

SAFE WORKING HOURS.

To determine safe working hours, comparison with other or previous large tunnel works of a similar nature must be made. The work on the Pennsylvania tunnel beneath the East River (1904–1909) was



DIVER WORKING IN TWO STAGES OF COMPRESSED AIR IN TUNNEL FLOODED BY "BLOW"—DIVING SUIT, HIGH-PRESSURE CHAMBER; TUNNEL, LOW-PRESSURE CHAMBER.



TUNNEL BULKHEAD SHOWING EMERGENCY LOCK AND MUCK LOCK.

well conducted; excellent records were kept, and Dr. F. L. Keays, who had charge of that particular work, obtained excellent results, considering the number of hours the men were forced to work at the time.

Comparison of hours of labor.

Public Service Commission tunnels.					Pennsylvania tunnel.				
Pressure.	Hours.	Shifts.			Pressure.	Hours.	Shifts.		
Pounds.		*Hrs. on.*	*Hrs. off.*	*Hrs. on.*	*Pounds.*		*Hrs. on.*	*Hrs. off.*	*Hrs. on.*
1 to 22	8	½ hour for lunch.			1 to 31	8	½ hour for lunch.		
22 to 30	6	3	1	3					
30 to 35	4	2	2	2					
35 to 40	3	1½	3	1½					
40 to 45	2	1	4	1	32 to 42	6	3	3	3
45 to 50	1½	¾	5	¾					

Comparison of number of cases of illness and percentage of cases based on number of decompressions at 40-pounds pressure.

Tunnel.	Number of decompressions.	Pressures.	Number of cases.	Percentage of cases.
		Lbs. per sq. in.		
Pennsylvania tunnel [a]	8,510	40	139	1.63
Public Service Commission tunnels	5,325	41	5	.094
	8,456	42	12	.142
	5,730	43	6	.105
	4,702	44	1	.021
	33,085	45	24	.073

[a] Keays, F. L., Compressed air illness: New York, 1909.

The above table shows that in the Pennsylvania tunnel, under a pressure of 40 pounds, for a period of one month, there was 1.63 per cent of compressed-air illness. In the Public Service Commission tunnels in pressures above 40 pounds during the entire work the percentage of cases scarcely exceeded 0.1 per cent.

EFFECT OF GASES.

CARBON DIOXIDE.

The question of the relation of increased amounts of CO_2 in compressed air to the number of cases of compressed-air illness has been discussed by all writers on the subject, and it is now conceded that the amount of CO_2 has no bearing whatever on the number of cases, except in so far as an atmosphere containing increased amounts of CO_2 accelerates respiration, thereby causing more rapid saturation of the blood and tissues with nitrogen. Haldane and Priestly [2] found that:

> With a pressure of 2 per cent of an atmosphere of CO_2 in the inspired air, the pulmonary ventilation was increased 50 per cent; with 3 per cent, about

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[2] Haldane, J. S., and Priestly, J. G., The regulation of lung ventilation: Jour. Physiol., vol. 32, 1905, p. 225.

100 per cent; with 4 per cent, about 200 per cent; with 5 per cent, about 300 per cent; with 6 per cent, about 500 per cent. With the last amount panting is severe, while with 3 per cent it is unnoticed until muscular work is done, when the pant is increased 100 per cent more than usual. With more than 6 per cent CO_2 the distress is very great, and headache, flushing, and sweating occur. With more than 10 per cent there is loss of consciousness after a time, but no immediate danger to life. Even 25 per cent CO_2 takes a long time to kill animals.

In considering the amount of CO_2 in compressed air, the partial pressure must be taken into account and not the percentage. For example, if the air when analyzed at normal pressure should show 0.5 per cent, in the same air at 30-pounds gage the partial pressure of the CO_2 would make the content equivalent to 1.5 per cent. During the Public Service Commission work, the CO_2 in the air as analyzed reached a partial pressure of 1 per cent only upon two or three occasions.

CARBON MONOXIDE.

Carbon monoxide is sometimes found in tunnels after blasting. On account of improvements in the quality of explosives used in recent years the quantity of carbon monoxide generated in tunnel headings by blasts has been reduced considerably. Men should not be permitted to work in an atmosphere containing any carbon monoxide, no matter how minute the quantity. The hæmoglobin in the blood has a great affinity for carbon monoxide and combines with it in the same way as with oxygen, but with an attraction approximately 250 times as strong. Accordingly, when even a trace of carbon monoxide is present in the air breathed the blood in time becomes partly saturated with this gas, making it impossible for the blood to take up the usual and necessary amount of oxygen. Disagreeable symptoms may develop when the men are exposed to 6 parts of carbon monoxide gas to 10,000 parts of air for an hour. Care must be taken that fresh air is supplied as near the working face of the tunnel as possible, and that the face is thoroughly cleared of gases after a blast, by opening the exhaust before the men are permitted to return to work.

OXYGEN POISONING.

Bert,[3] after analyzing the blood of animals dying from oxygen poisoning, found that the oxygen in the blood exceeded 30 per cent. Blood takes up one-half of 1 per cent of oxygen for each atmosphere of air, so that in pure oxygen at a pressure of one atmosphere the blood would take up approximately 2.5 per cent. After the hæmoglobin has taken up all the oxygen it possibly can, the balance of the oxygen is dissolved in the blood serum, which is delivered to

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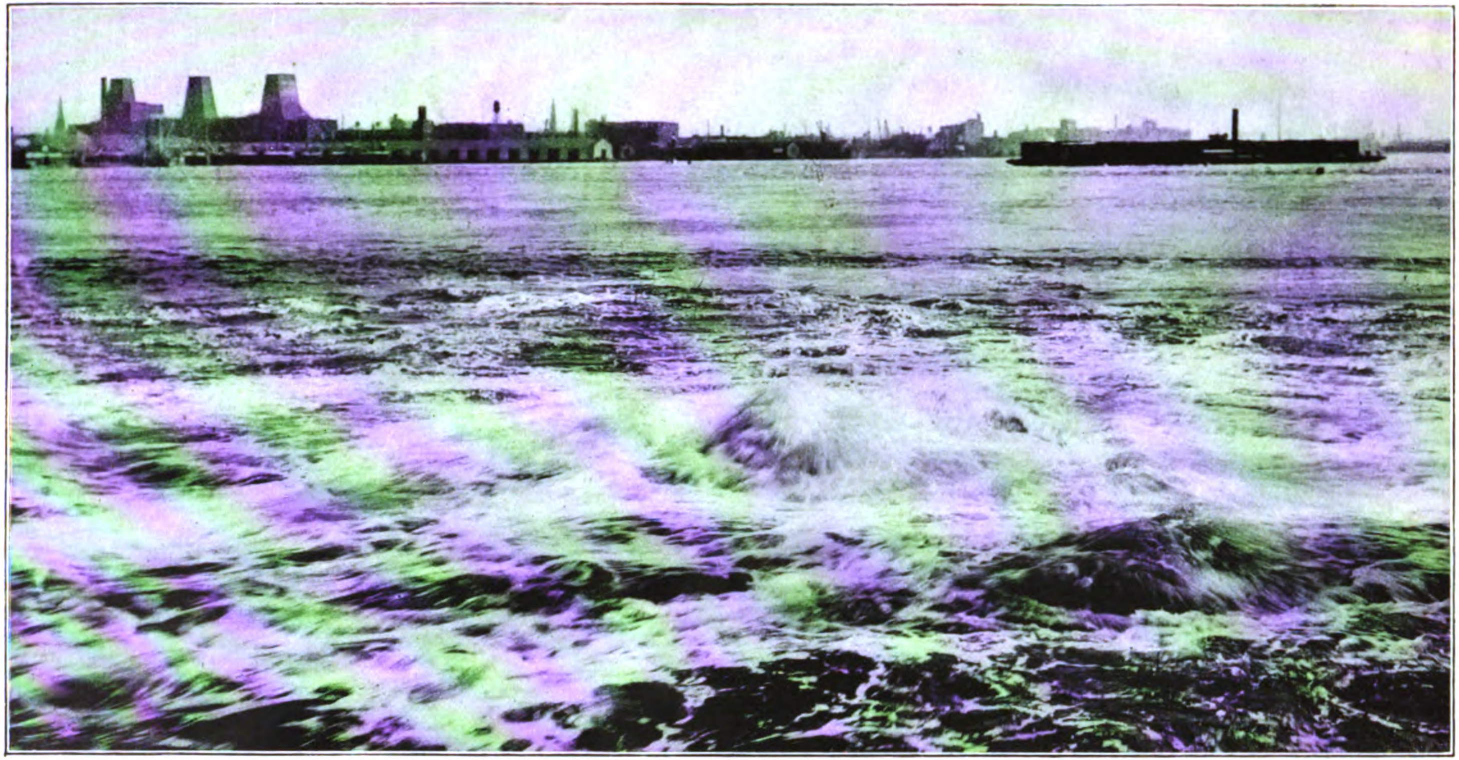
[3] Bert, Paul, La pression barométrique, recherches de physiologie expérimentale: Paris, 1878, pp. 601-606.



"BLOW" IN EAST RIVER, NEW YORK, FROM ONE OF THE PUBLIC SERVICE COMMISSION TUNNELS UNDER CONSTRUCTION BENEATH THE RIVER BED.

the tissues; therefore when the oxygen percentage becomes too high, cerebral irritation takes place, and convulsions may occur. Bert states that all living things perish in oxygen at a pressure corresponding to 20 atmospheres of air.

Hill,[3a] in confirming the results of Lorrain Smith, states that "high partial pressure of oxygen exercises a marked irritant effect on the lungs, producing at first congestion of the alveolar capillaries, and afterwards haemorrhagic exudation and consolidation."

NITROGEN.

Haldane and Smith[4] have estimated that the blood is 5 per cent of the body weight; and Haldane[5] has shown that it takes approximately one minute for the blood to return to the heart. During compression, the blood while going through the lungs takes up nitrogen to its point of saturation, which increases approximately 1 per cent for every additional atmosphere of pressure applied. This nitrogen-saturated blood in its circuit about the body delivers its nitrogen to the less saturated tissues and fluids and returns to the heart ready to be resaturated and again deliver its nitrogen to the tissues. If all parts of the body had an equal blood supply and the blood were considered as one-twentieth of the body weight, in 20 complete circulations of the blood the entire body would theoretically be saturated with nitrogen; that is, if the blood returned desaturated each trip and was then fully saturated from the lungs. As a matter of fact, this does not take place. The blood returns to the heart each time with a saturation equal to that of the tissues, so that with each trip less nitrogen can be taken up by the blood and less can be delivered to the tissues. Moreover, the body is composed of 20 parts of fat, and fat has been shown by Vernon[6] to take up five times as much nitrogen as the ordinary body fluids, making a body bulk of nine-fifths as far as saturation is concerned. It has, therefore, been estimated by Von Schrotter[7] that the relative ratio of blood to body weight would be 1 to 35 instead of 1 to 20; furthermore, the blood supply to the fat being comparatively poor, full saturation must require much more time. Haldane[8] has calculated that half saturation takes place in 15 minutes and almost complete saturation in 1 hour. When the circulation is increased by labor of any kind, saturation will be much more rapid and will depend upon the increased rapidity of the heart action.

[3a] Hill, Leonard, Caisson sickness, p. 136.

[4] Haldane, J. S., and Smith, J. L., The mass and oxygen capacity of the blood in man: Jour. Physiol., vol. 25, 1900, pp. 331–343.

[5] Haldane, J. S., Report to the Lords Commissioners of the Admiralty on deep-water diving: London, 1907.

[6] Vernon, H. M., The production of prolonged apnœa in man: Jour. Physiol., Proceedings, vol. 36, 1909, pp. xviii–xx.

[7] Von Schrotter, Leopold, Luftdruck Erkrankungen: Vienna, 1900.

[8] Haldane, J. S., Report to the Lords Commissioners of the Admiralty on deep-water diving: London, 1907.

In decompression, the action taking place is the reverse of that explained above. The supersaturated tissues give off nitrogen to the blood, which is desaturated by going through the lungs. Then the blood is again saturated with nitrogen from the tissues and desaturated in the lungs, and so on until equilibrium with the normal atmosphere is established. Should the decompression be so rapid as not to permit enough time for the blood to carry the nitrogen freed from the tissues to the lungs or should the lungs be incapable of ridding the blood of the excess nitrogen, gas bubbles of nitrogen will form in the body fluids and tissues. This formation of gas bubbles is the accepted theory at present of the cause of caisson disease.

SYMPTOMS OF COMPRESSED-AIR ILLNESS.

In order to make comparisons with previously reported work, the writer has endeavored to use the same classifications of compressed-air illness as others have used, namely, affections of the nervous system, localized pain, vertigo, "chokes" or dyspnea, unconsciousness, and collapse. The symptoms depend on the quantity of free gases and the places of lodgment of these gases in the tissues.

1. *Affections of the central nervous system.*—Disturbances of the central nervous system may be either motor or sensory, due to the pressure of air emboli upon the brain or spinal cord.

2. *Localized pains.*—Localization of pain depends on whether the gas emboli are present in the muscle fiber, tendon sheath, bone, or nerve terminal.

3. *Vertigo.*—Dizziness is the result of gas emboli in the middle ear or may be caused by disturbances of the central nervous system.

4. "*Chokes.*"—Difficult breathing is due to bubbles of gas forced through the pulmonary arteries into the lungs.

5. *Unconsciousness or collapse.*—Unconsciousness or collapse is usually caused by large quantities of gas distributed generally throughout the circulation.

No cases of local swelling, such as have been reported by Dr. Keays,[9] were observed by the writer. The sensation of "puces" and painful itch, probably due to air bubbles in the subcutaneous tissue, is common among caisson workers, but no special significance has been attached to it.

Cases classified as localized pain, vertigo, and "chokes" can usually be relieved by recompression. The symptoms due to affections of the central nervous system can ordinarily be relieved by immediate recompression, but if recompression is postponed de-

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[9] Keays, F. L., Compressed-air illness: New York, 1909.

Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

struction of the nerve elements may result, and more or less permanent injury is to be expected. Unconsciousness and collapse with abdominal pain, in which a comparatively large amount of air is present in the circulation, indicate grave danger, although if treatment is prompt recovery should follow. The writer is convinced that compressed-air illness could be limited to cases of localized pain if the hours of labor are properly adjusted and a reasonable length of time for decompression is permitted.

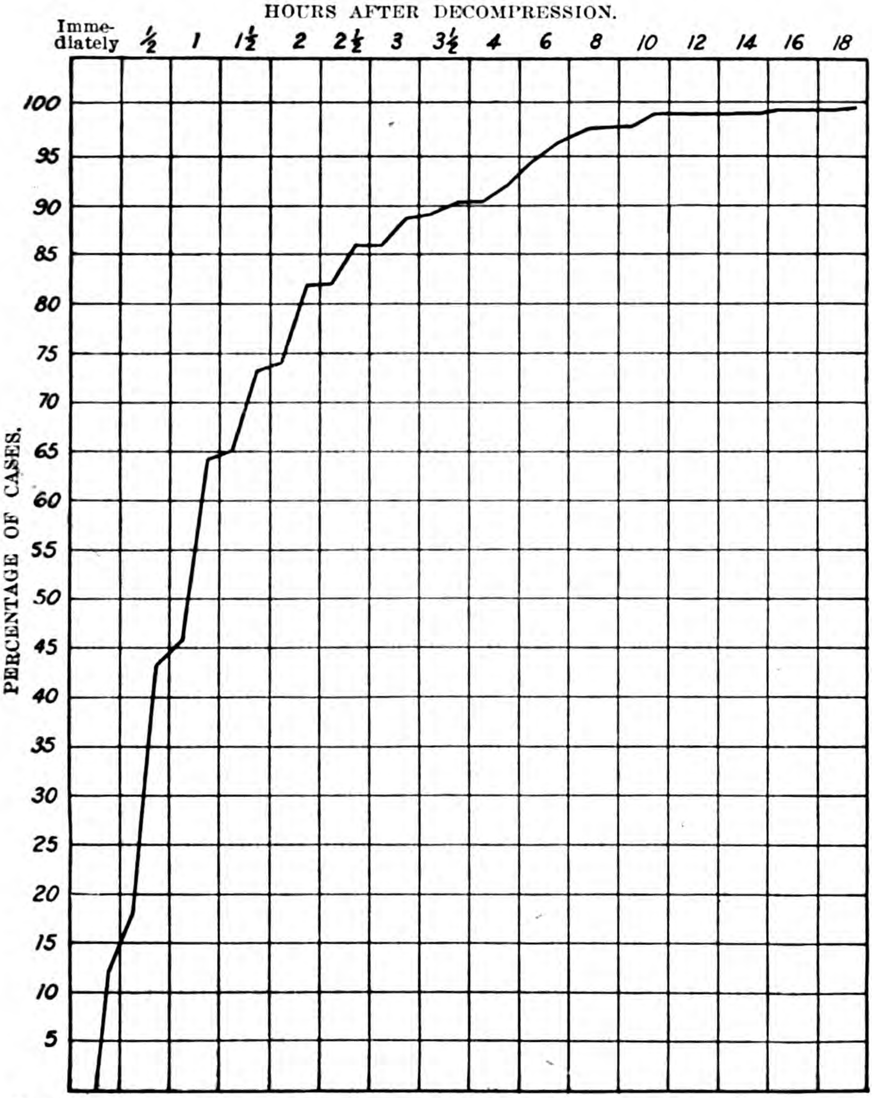

FIGURE 8.—Percentage of reported cases of compressed-air illness in relation to the number of hours after decompression before illness set in.

In order to prevent the ear passages from becoming blocked, each man entering compressed air on his initial trip should be instructed to swallow or to use the Valsalva method of inflating the middle ear by closing both nostrils with the thumb and forefinger, shutting the mouth firmly, and then making a strong expiratory effort. In this way he expels air from the nasal pharynx to such an extent that it opens up the Eustachian tubes. Even this method is sometimes unsuccessful with men suffering from a coryza (cold in the head). When equalization of the pressure does not take place from within, severe pain occurs from the stretching of the eardrum, and if the pressure is increased to a certain point the eardrum finally ruptures. When a man who is being locked in withstands the pressure to a certain point before his ears become blocked, decreasing the pressure in the air lock for a short time will relieve the pressure in the middle ear, the Eustachian tube may open, and the air pressure may be restored without the ears again becoming blocked.

With reference to the onset of symptoms, the writer found that of 680 cases of compressed-air illness in the Public Service Commission tunnel work only 436 were accurately reported. Of these 436 cases, 280, or 64.2 per cent, occurred within the first hour after decompression; 77, or 17.7 per cent, in the second hour; 30, or 6.9 per cent, in the third hour; 14, or 3.2 per cent, in the fourth hour; and 33, or 7.6 per cent, between the fourth and eighteenth hours (see fig. 8). The records for the Pennsylvania tunnels show a greater percentage of cases in which symptoms were manifested within the first hour after decompression, than those for the Public Service Commission tunnel work, the figures for the former being 85.9 per cent and for the latter 64.2 per cent. Inasmuch as the Pennsylvania records include a greater number of cases, the writer is inclined to believe that its figures are nearer the average. Although the writer observed no cases in which the onset of symptoms occurred after 18 hours, the Pennsylvania records show cases occurring 23 hours after decompression.

ANALYSIS OF COMPRESSED-AIR ILLNESSES REPORTED.

In the 1,361,461 decompressions during the Public Service Commission tunnel work there were 680 cases of compressed-air illness, 624, or 91.8 per cent, of which were cases of localized pain; 44, or 6.5 per cent, were cases of vertigo; 11, or 1.6 per cent, cases of central nervous system affections; and 1 case of dyspnea, or 0.1 per cent. Of the 624 cases of localized pain, 335, or 49.3 per cent of the entire number showed only one joint involved; in 251, or 36.9 per cent, of all cases there was multiple joint involvement; in 38, or 5.6 per cent of all cases, there were body or head pains. Only one case of localized pain, in which the pain was in the abdomen and collapse occurred, was fatal. This man worked in a 33-pound pressure, and the time for decompression was 22 minutes. He was attacked with pain in the abdomen, became unconscious one hour later, and died in 10¾ hours. Of the 11 men, or 1.6 per cent, whose central nervous systems were affected, all recovered completely except two, both of whom had a paraplegia. Although these men are up and about, they still show the result of the injury to the spinal cord. All the cases of vertigo and vomiting recovered shortly after recompression. The case of dyspnea or chokes occurred in a man who was a walking boss. He was careless in decompression; an attack of chokes came on two hours after locking out, and he died one hour later.

In the two deaths in this series of cases autopsies showed large quantities of free gas in practically all veins of the body. A peculiar condition was found in the small intestines. The mucous membrane had the appearance of small grains of tapioca placed closely together in patches, due to the presence of small bubbles of air in the submucous layer. This may explain the cases that show prostration and severe pain in the abdomen.

The following table shows the parts of the body that were affected in the different types of illness.

Record of 680 cases of compressed-air illness, showing parts of body affected.

Central Nervous System.

Paralysis of left leg	2
Paralysis of right leg	1
Paralysis of both legs	2
Numbness of side and arm	1
Numbness of right leg	1
Numbness of legs and weakness of knees	1
Numbness of arms and legs and mottling of skin	1
Pain in hips, with retention of urine	1
Pain in abdomen, with retention of urine	1
Total, central nervous system (1.6 per cent)	**11**

Localized Pain in Body.

SINGLE JOINT.	
Shoulder	14
Arm	52
Elbow	10
Wrist	4
Hand	1
Hip	3
Thigh	6
Knee	209
Leg	33
Ankle	3
Total (49.3 per cent)	**335**

MULTIPLE JOINTS.	
Shoulders	1
Shoulders and arms	3
Shoulders, elbows, and wrists	1
Shoulders, arms, and knees	1
Shoulders and knees	1
Shoulders, elbow, and knee	3
Shoulder and knee	11
Shoulder and hip	1
Shoulder and biceps	1
Shoulder and chest	1
Shoulder, elbow, and wrist	2
Shoulder, elbow, and arm	9
Arms	6
Arms and legs	9
Arms and knees	16
Arm and leg	5
Arm and knee	4
Elbows and wrists	1
Elbows and knees	4
Elbow and arm	1
Elbow and biceps	1
Elbow and knee	5
Wrists	1
Wrist and knee	3
Hands and knees	1
Hand and knee	1
Hips	2
Hips and knees	2
Hip and knee	6
Hip, thigh, and knee	2
Thighs and knees	1
Thigh and knee	6
Thigh, knee, and leg	3
Knees	91
Knees and legs	5
Knees and ankles	6

Localized Pain in Body—Continued.

MULTIPLE JOINTS—continued.	
Knee and calf	5
Knee and leg	7
Knee and ankle	3
Legs	19
Total (36.9 per cent)	251
BODY.	
Head	3
Head and knees	1

BODY—continued.	
Chest	5
Back	1
Abdomen	20
Abdomen and discoloration	1
Abdomen and collapse (death)	1
Abdomen and arms	2
Abdomen and knees	2
Abdomen and leg	1
Abdomen and lower extremities	1
Total (5.6 per cent)	38

SUMMARY OF LOCALIZED PAIN.

	Total.	Per cent.
Single joint	335	49.3
Multiple joints	251	36.9
Body	38	5.6
Total, localized pain	624	91.8

Vertigo.

Vertigo	36
Vertigo and vomiting	4
Vertigo and pain in legs	1
Vertigo and pain in arms	1
Vertigo and pain in arms and legs	1
Vertigo and pain in all joints	1
Total (6.5 per cent)	44

Chokes.

Chokes (death)	1, or .1 per cent.

SUMMARY OF THE 680 CASES.

	Cases.	Per cent.
Central nervous system	11	1.6
Localized pain in body	623	91.7
Vertigo	44	6.5
Chokes	1	0.1
Collapse [a]	1	0.1
	680	100.0

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[a] Included under heading, "Localized pain in body."

While the Public Service Commission tunnels were being built 680 cases, or 0.05 per cent, of caisson illness were reported out of 1,361,461 decompressions, and in the Pennsylvania tunnels 3,692 cases, or 0.66 per cent, were reported out of 557,000 decompressions. The following comparison of the different groups of these cases is given to show the similarity of the percentages of the various types of illness.[10]

Comparison of types of illness.

		Pennsylvania tunnels.	Public Service Commission tunnels.
Central nervous system	per cent	2.16	1.6
Localized pain in body	do	90.30	91.7
Vertigo	do	5.33	6.5
Chokes	do	1.62	0.1
Partial or complete unconsciousness with collapse	do	0.46	0.1

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[10] Keays, F. L., Compressed-air illness: New York, 1909.

Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TREATMENT OF COMPRESSED-AIR ILLNESS.

Long before any great American projects requiring the use of compressed air were undertaken it was recognized that recompression was the correct treatment for compressed-air illness. Experiments of previous observers have shown that when a frog was put in a chamber of air and compressed, then rapidly decompressed, a light thrown on the web of its feet and the circulation observed under a microscope, bubbles of air were visible; when the pressure was again raised to its previous height the bubbles were seen to grow smaller and disappear. These observations of a previously known physical condition indicate that recompression is the logical treatment, and to obtain the best results it must be done before the bubbles of nitrogen can permanently injure the tissues.

Inasmuch as many of the Public Service Commission workers lived at a considerable distance from the work, arrangements were made with the Department of Charities, which controlled the ambulance service in the city of New York, that if the men were taken sick in any borough of New York the ambulance surgeon would not take these cases to a hospital but would rush them to the nearest medical lock for treatment. Each employee was given a badge which it was obligatory to wear at all times and on which was printed the location of the medical locks.

A worker suffering from compressed-air illness should be put in a medical lock and the pressure rapidly raised to that in which he had previously worked. It is a good policy to keep the patient at this pressure for a short time in order to be sure that the bubbles of nitrogen have been thoroughly compressed and again taken up by the circulation. The patient may then be decompressed again by the stage method, except that now the time should be double in every part of the decompression. Although symptoms are frequently relieved before the pressure in which the man had worked is reached, the writer believes that it is safer to attain the original pressure before decompressing.

In affections of the spinal cord it is very important that full time be given to treatment by compression. If the symptoms are not relieved by the first recompression, a second and, if necessary, a third recompression may be given. Of the 680 cases of compressed-air illness all were more or less relieved; in a few isolated instances pain persisted for a short time. The two cases of paralysis were only partly relieved, but if the recompression period had been longer better results might have been obtained. It is always advisable to have the patient exercise, if possible, and thereby stimulate the circulation during recompression. The giving of oxygen toward the end of decompression, as recommended by some authorities, may possibly be of some service in hastening the desaturation of the tissues. It is understood that the regular medical treatment usually given in cases of collapse should be administered while the patient is being decompressed.

The medical airlock (Plates XII and XIII) used in connection with compressed-air work is a steel cylinder 6 feet in diameter and 18 feet 6 inches in length; one end is entirely closed and the other end has an entrance door opening inward. The cylinder is divided into two compartments of equal size by a partition with a door that opens toward the inner compartment. The inner compartment is fitted with a cot, on which the patient may lie if necessary. The lock has electric lights, telephone, clock, pressure gage, thermometer, electric heater, and appropriate medical equipment. Suitable provision is made for ventilation. The compressed-air pipes and outlet valves are so arranged that the pressure in either of the compartments can be regulated from outside the medical lock, or either compartment may be regulated from the one in which the operator happens to be. The distant lock can be regulated by its own valves. Heavy glass windows, of the bull's-eye type, are placed in line over both doors and at the closed end, so that the patient, pressure gage, and thermometer can be watched from the outside.

STAGE METHOD OF DECOMPRESSION.

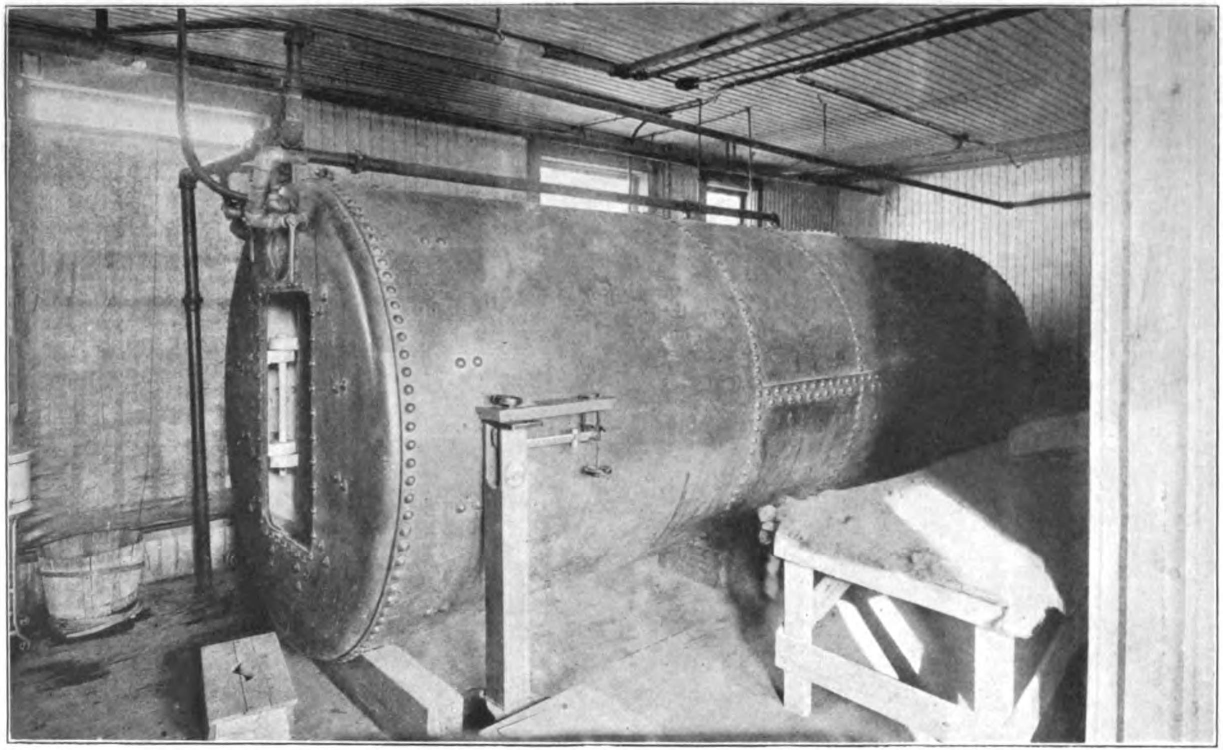
It would seem that the stage method of decompression might be made safer by dropping to half the gage pressure instead of half the absolute pressure as recommended by Haldane, Japp, and others. In the tunnels of the Public Service Commission, a drop was made from 40 to 20 pounds; the men were kept in 20 pounds pressure for a certain length of time; then a prolonged uniform decompression was used.

PRECAUTION IN LOCKING OUT.

As a drop of 20 pounds in a very short period causes a rapid fall in temperature, the men must be impressed with the necessity of taking extra clothing into the lock in order to avoid chilling. While in the lock, they should take exercise to help stimulate the circulation and thus cause more rapid desaturation.

AFTER EFFECTS OF WORK IN COMPRESSED AIR.

An analysis of the records reveals that of the 671 Public Service Commission engineers, who were carefully examined for compressed-



MEDICAL AIR LOCK USED FOR THE TREATMENT OF COMPRESSED-AIR ILLNESS.

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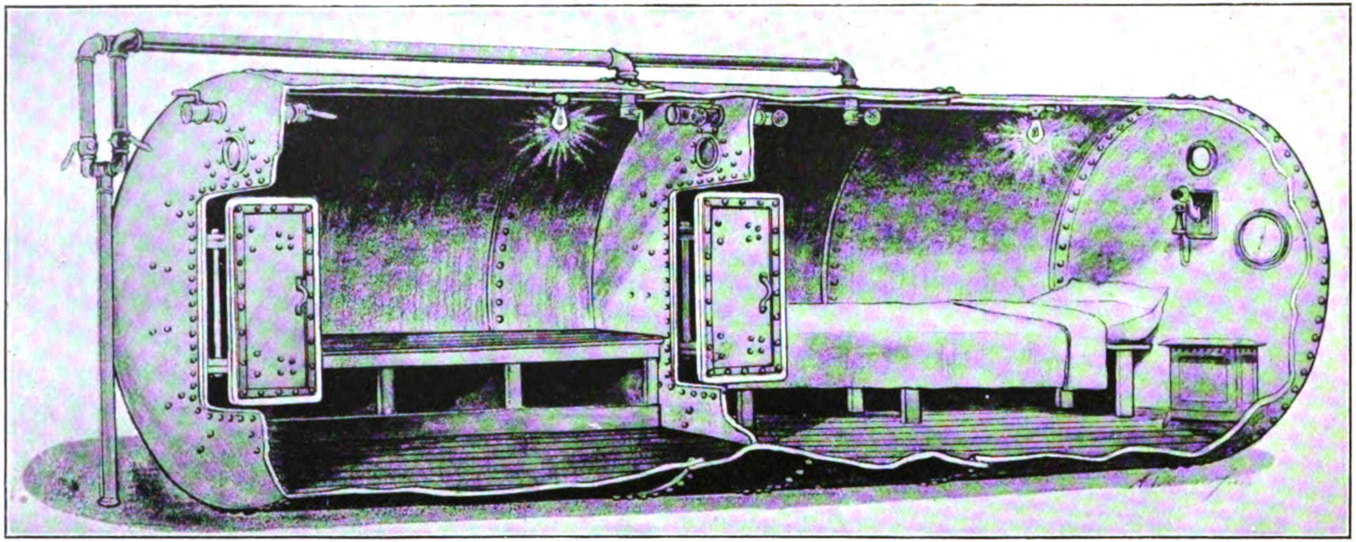

INTERIOR OF THE MEDICAL AIR LOCK.

air work, five developed tuberculosis within one year of the termination of the work, while of the 2,664 employees who were only superficially examined before they were engaged in noncompressed-air engineering work, none developed tuberculosis within the year. Of the 680 cases of compressed-air illness, the two cases of paralysis resulted in permanent disability.

Some authors are inclined to think that because the men are working under higher oxygen pressures less hæmoglobin is needed to carry blood to the tissues, and that continued working in increased oxygen pressure is apt to cause anæmia. The writer has observed many symptoms of anæmia in men who have worked in compressed air for some time and believes this condition is secondary to a general disturbance in the method of living of these men. They work in shifts during the entire 24 hours; for a month or two they work on the day shift, then they are assigned to the night shift. It takes men a long time, with changing shifts, to become accustomed to the change in eating and sleeping hours. They all grumble about it, and this alteration in mode of life may have much to do with the staleness of which they complain. It might be better to keep men on the shifts to which they have become accustomed.

REGULATIONS AND SAFETY MEASURES.

Few States have legislative measures protecting the welfare of men working in compressed air. From the best information that the writer has been able to accumulate, only three States—New York, New Jersey, and Pennsylvania—have any laws regulating the hours of labor and the hygienic conditions to be observed in such work.

NEW YORK.

The State of New York, in which so much construction work has been done, involving the use of compressed air, has made more progress than other States in promulgating laws for the protection of this class of workers. In New York the 20 tubes listed below have already been built under compressed air.

Tunnels built with the aid of compressed air in the vicinity of New York City.

Tunnel.	Number of tubes.	Year.	Contractor.	Distance between shafts.	Maximum pressure.	Number of decompressions.	Cases of bends.	Deaths.
				Feet.	*Pounds.*			
[a] Hudson-Manhattan.	4	1874 1903–1907	Hudson Companies...	5,650	42	(?)	1,573	3
[b] Battery-Joralemon.	2	1902–1908	New York Tunnel Co.	4,650	42	(?)	(e)	14
[c] North River-Pennsylvania.	2	1903–1909	O'Rourke Engineering Construction Co.	6,590	28	(?)	(f)	(?)
[c] East River-Pennsylvania.	4	1904–1909	F. Pearson & Sons Co..	3,916	42	557,000	3,692	20
[d] Clarke Street.....	2	1914–1919	Flinn-O'Rourke Co..	3,811	37½	761,405	292	1
[d] Montague Street..	2	1914–1919	.....do................	4,010	34½			
[d] Fourteenth Street.	2	1916–1921	Booth & Flinn (Ltd.).	3,436	39½	388,096	270	....
[d] Sixtieth Street....	2	1917–1921	P. McGovern & Co...	3,551	47½	211,960	118	1

[a] Information from Mr. J. V. Davies, consulting engineer, New York.

[b] Records of board of rapid transit commissioners.

[c] Keays, F. L., Compressed-air illness: New York, 1909.

[d] Records of public service commission.

[e] In 5 months when records were kept, 674; sometimes 25 a day.

[f] 490 well-marked cases.

The last four tunnels were built under the supervision of the Public Service Commission for the First District. The contractors employed their own physicians, who had direct charge of the men, the entire work being under the supervision of the commission.

Work has been started on a twin vehicular tunnel beneath the Hudson River. A large tunnel under the Narrows is under consideration.

For the purpose of revising the old rules and regulations governing work in caissons and tunnels the New York State Department of labor appointed a committee composed of several representatives from each of the following groups: Contractors engaged in caisson and tunnel work, the compressed-air workers' union, the Public Service Commission (which supervised the building of the East River tunnels), the Industrial Commission, and a number of insurance companies. This committee has ended its work, and the new regulations which it formulated have been enacted into law, becoming effective March 1, 1920. These rules and regulations provide for proper platforms and cables and the care of explosives, and also regulate matters pertaining to medical supervision. The medical rules, with comments by the writer on the changes that have been made in the old rules with regard to medical supervision, are given in the paragraphs below:

REGULATIONS OF NEW YORK STATE LABOR DEPARTMENT.

1. *Hours of labor. Rule 1151.* Hours of labor shall be as follows:

(*a*) When the air pressure in any compartment, caisson, tunnel, or place in which men are employed is greater than normal and less than 22 pounds to the

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square inch, no employee shall be permitted to work or remain therein more than eight hours in any twenty-four hours, and shall be permitted to work under such air-pressure only if he shall during such eight hours return to the open air for an interval of at least thirty consecutive minutes, which interval his employer shall provide for.

(*b*) When the air pressure in any compartment, caisson, tunnel, or place in which men are employed is 22 pounds or over and less than 30 pounds to the square inch, no employees shall be permitted to work or remain therein more than six hours in any twenty-four hours, such six hours to be divided into two periods of three hours each, with an interval of at least one hour between such periods.

(*c*) When the air pressure in any such compartment, caisson, tunnel, or place is thirty pounds or over and less than thirty-five pounds to the square inch no employee shall be permitted to work or remain therein more than four hours in any twenty-four hours, such four hours to be divided into two periods of two hours each, with an interval of at least two hours between such periods.

(*d*) When the air pressure in any such compartment, caisson, tunnel, or place is thirty-five pounds or over and less than forty pounds to the square inch, no such employee shall be permitted to work or remain therein more than three hours in any twenty-four hours, such three hours to be divided into periods of not more than one and one-half hours each with an interval of at least three hours between such periods.

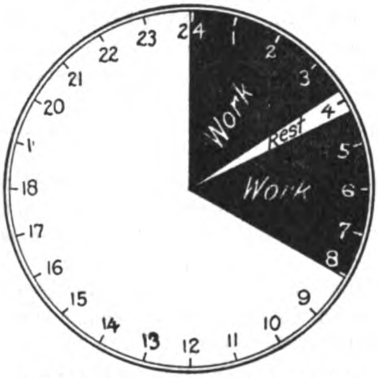
(*e*) When the air pressure in any such compartment, caisson, tunnel, or place is forty pounds or over and less than forty-five pounds to the square inch, no employee shall be permitted to work or remain therein more than two hours in any twenty-four hours, such two hours to be divided into periods of not more than one hour each, with an interval of at least four hours between such periods.

(*f*) When the air pressure in any such compartment, caisson, tunnel, or place is forty-five pounds or over and less than fifty pounds to the square inch, no employee shall be permitted to work or remain therein more than ninety minutes in any twenty-four hours, such ninety minutes to be divided into two periods of forty-five minutes each, with an interval of not less than five hours between such periods.

The limits of hours as herein specified shall apply according to the maximum pressure attained at any time during any period.

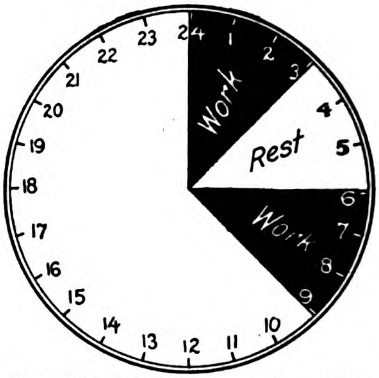
Rule 1151, relating to hours of labor, has not been changed except in one particular. Under the old rules no man was permitted to work in compressed air where the pressure exceeded 50 pounds, save in an emergency; this restriction has been removed and does not appear in the new rules. As the writer suggested early in this article (see p. 14), some advantage might accrue from changing the shifts at 29 instead of at 30 pounds, and at 34 instead of at 35 pounds, but inasmuch as none of the cases of illness occurring at 29 and 34 pounds were severe it has been thought inadvisable to shorten the hours of labor more than is absolutely necessary, as the cost of tunneling is very high, even under the old rules. The accompanying chart (fig. 9) shows how much of the 24 hours is spent in work in the various pressures.

0 to 22 pounds.



8 hours, with an interval of ½ hour.

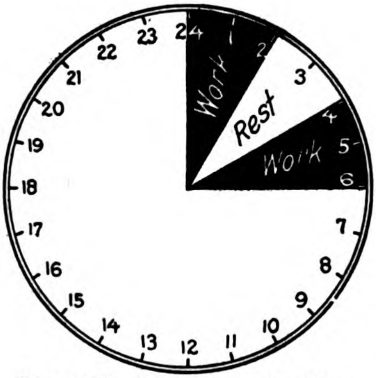
22 to 30 pounds.



Two shifts of 3 hours each, with an interval of 3 hours.

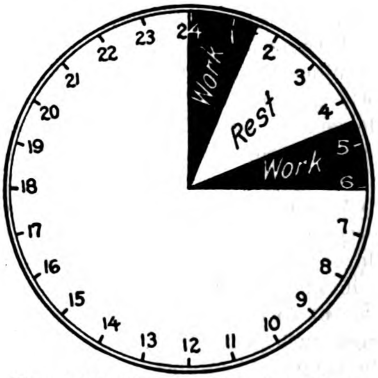
Labor law prescribes a minimum of 1 hour.

30 to 35 pounds.



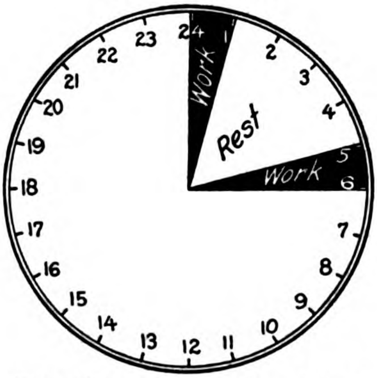
Two shifts of 2 hours each, with an interval of 2 hours.

35 to 40 pounds.



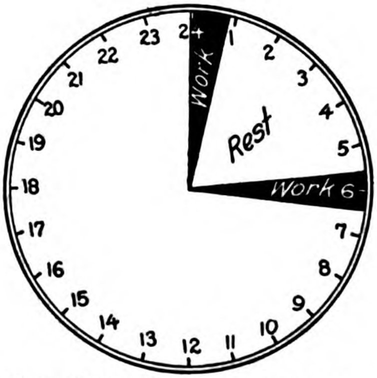
Two shifts of 1½ hours each, with an interval of 3 hours.

40 to 45 pounds.



Two shifts of 1 hour each, with an interval of 4 hours.

45 to 50 pounds.



Two shifts of ¾ hour each, with an interval of 5 hours.

FIGURE 9.—Lengths of shifts with periods of rest in various pressures, as regulated by the State Department of Labor.

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2. *Decompression. Rule 1152.* No person employed in compressed air shall be permitted to pass from the place in which the work is being done to normal air, except after decompression in the intermediate lock, as follows:

> A stage decompression shall be used in which a drop of one-half of the maximum gage pressure shall be at the rate of five pounds per minute. The remaining decompression shall be at a uniform rate, and the total time of decompression shall equal the time specified for the original maximum pressure.

(*a*) Where the air pressure is greater than normal and less than fifteen pounds to the square inch, decompression shall be at the minimum rate of three pounds per minute.

(*b*) Where the air pressure is fifteen or over and less than twenty pounds to the square inch, decompression shall be at the minimum rate of two pounds per minute.

(*c*) Where the air pressure is twenty pounds or over and less than thirty pounds to the square inch, decompression shall be at the minimum rate of three pounds every two minutes.

(*d*) Where the air pressure is thirty pounds or over to the square inch, decompression shall be at the minimum rate of a pound per minute.

The time of decompression shall be posted in each man lock.

In Rule 1152 slight changes have been made. In paragraph *d* the old law called for "decompression at the minimum rate of three pounds every two minutes up to 36 pounds, and where the air shall reach 36 pounds at the minimum rate of one pound per minute." The accompanying chart (fig. 10, p. 34) shows the decompression time from each pound pressure.

3. *Gages. Rule 1153.* When the pressure exceeds seventeen pounds to the square inch, when practicable to do so, a recording gage to show the rate of decompression shall be attached to the exterior of each man lock. The dial shall be of such size that the amount of rise or fall in the air pressure within any five minutes shall be readily shown.

There shall be on the outer side of each working chamber at least one back-pressure gage which shall be accessible at all times, and shall be kept in accurate working order. Additional fittings shall be provided so that test gages may be attached at all necessary times. Back-pressure gages shall be tested every twenty-four hours and a record kept of such tests.

A competent man shall be placed in charge of the valves and gages which regulate and show the pressure in the working chamber. He shall not be employed more than eight hours in any twenty-four. At no time shall he operate more than two separate air lines.

Rule 1153. Owing to the fact that the method of decompression is never carried out by any fixed rule, each lock tender having his own method of using the allotted time, it was thought advisable to install a recording gage to show any mistakes of the lock tender in order that he might profit thereby.

4. *Exhaust valves. Rule 1167.* Exhaust valves shall be provided, having risers extending to the upper part of the chamber, if necessary, and shall be operated at such times as may be required and especially after a blast, and

men shall not be required to resume work after a blast until the gas and smoke have cleared.

Rule 1167 should be enforced strictly.

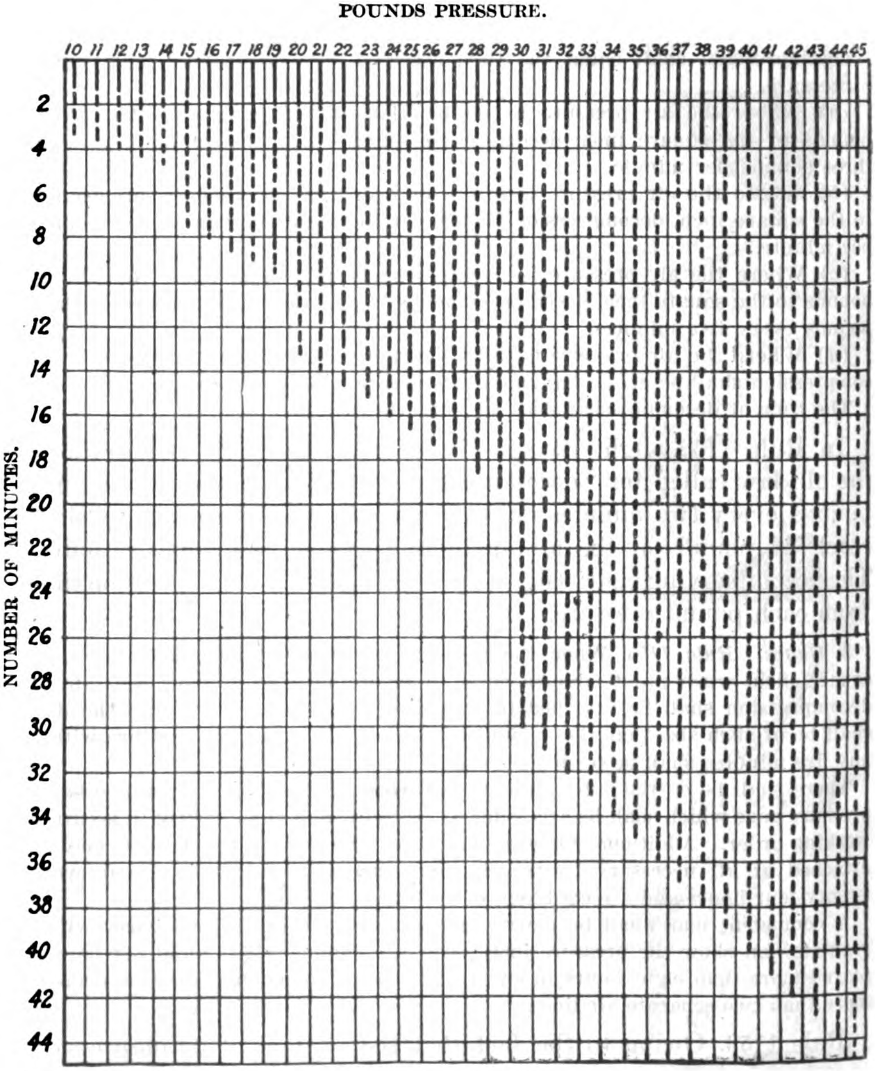

FIGURE 10.—Time required for decompression from the various pressures, as prescribed by the New York State Department of Labor, effective March, 1920. Solid lines indicate a drop of one-half the pressure at the rate of 5 pounds a minute; broken lines a uniform rate of decompression for the remaining prescribed time.

5. *Wash and rest rooms. Rule 1170.*

(*a*) Lockers. All men shall have individual lockers of reasonable size, preferably metal lockers.

(*b*) Dry room. A separate dry room shall be provided where working clothes may be dried within reasonable time. This room shall be well heated.

(*c*) Baths. One shower bath fitted with regulating valves shall be provided for every eight men coming off shift.

(*d*) Washbasins. One basin and stopper shall be provided for every eight men coming off shift. Running water shall be supplied.

(*e*) Toilets. One toilet and one urinal shall be provided for every twenty men employed on each shift.

(*f*) Water supply. A sufficient amount of hot and cold water shall be supplied at all times.

(*g*) Temperature. A minimum temperature of 70 degrees Fahrenheit shall be maintained at all times in wash and dressing rooms.

(*h*) Coffee and utensils. A sufficient supply of hot coffee and sugar shall be supplied to men working in compressed air at the termination of shifts and during rest periods. Coffee must be heated by means other than direct steam. Coffee containers and cups shall be kept in a clean and sanitary condition at all times. All containers shall be kept covered at all times.

Most of the provisions of rule 1170 are new and speak for themselves. With reference to paragraph *h*, relating to coffee, the writer personally believes that a hot drink is all that the men require and that the taking of too large quantities of coffee daily is apt to cause more or less gastric disturbance.

6. *Sanitation and ventilation. Rule 1171.* Absolutely no nuisance shall be tolerated in the air chamber; containers shall be provided when necessary.

No smoking shall be permitted in the air chamber.

No animals shall be permitted in the air chamber.

The supply of fresh air to the working chamber shall be sufficient at all times to permit work to be done without danger or discomfort. All air supply lines shall be supplied with check valves and carried as near to the face of the tunnel as practicable. The air shall be analyzed by the contractor as required and a record kept of the same.

Care shall be taken to keep all parts of tunnel, caissons, and other working compartments, including lockers, dry rooms, rest rooms, and other equipment in a sanitary condition and free from refuse or decaying matter.

7. *Medical attendance and regulations. Rule 1172.* Any person or corporation carrying on any work in the prosecution of which men are employed or permitted to work in compressed air, shall employ one or more duly licensed physicians, who shall have had experience in compressed-air work, whose duty it shall be to strictly enforce the following:

(*a*) No person shall be permitted to work in compressed air before he shall have been examined by the physician and reported to the person in charge thereof to be physically fit to engage in such work.

(*b*) In the event of absence from work of an employee for ten or more successive days for any cause, he shall not resume work until he shall have been reexamined by a physician and his physical condition reported to be such as to permit him to work in compressed air.

(*c*) No person known to be addicted to the excessive use of intoxicants shall be permitted to work in compressed air.

(*d*) No person not having previously worked in compressed air shall be permitted to work in a pressure exceeding seventeen pounds without having first been tested by the physician in the medical lock, nor shall any such person be permitted to work under any pressure for longer than one-half of a day period until he shall have been reexamined by the physician and found to be physically fit for such work.

(*e*) After a person has been employed continuously in compressed air for a period of two months, he shall be reexamined by the physician, and he shall not be permitted to work until such reexamination has been made and he has been reported as physically qualified to engage in compressed-air work.

(*f*) The physician shall at all times keep a complete and full record of examinations made by him, which records shall contain dates of which examinations were made and a clear and full description of the person examined, his age and physical condition at the time examined, also a statement as to the time such person has been engaged in like employment. A uniform examination blank, which shall contain the record of examinations in every case of compressed-air workers, shall be used by each medical examiner, and the record of such examinations shall be kept on file at the place where the work is in progress and shall be subject to inspection by the Industrial Commission.

(*g*) A medical lock shall be established and maintained in connection with all work in compressed air when this maximum pressure exceeds seventeen pounds. Such locks shall be not less than five feet in height and shall be divided into two compartments. Each door shall be provided with a bull's-eye and fitted with air valve so arranged to be operated from within and without. Such lock shall be kept properly heated, lighted, and ventilated and shall contain a gage, a telephone, and a cot. Such lock shall be under the control of the physician in charge, and there shall be maintained in close proximity a first-aid room, which shall contain a bathtub and all medical and surgical appliances necessary for first aid in case of accident.

(*h*) An identification badge shall be furnished to all employees advising police officials that the employee is a compressed-air worker, stating location of medical lock, and stating that in case of emergency an ambulance surgeon shall remove the patient to the medical lock and not to the hospital.

(*i*) All cases of compressed-air illness shall be reported to the Industrial Commission on a uniform blank furnished by the commission, and copies of all such reports shall be kept on file.

(*j*) When the air pressure exceeds seventeen pounds or when fifty or more men are employed, the physician herein required shall be in attendance at all times while the work is in progress.

In reference to Rule 1172, the clause "shall have had experience in compressed-air work" may seem a hardship, but will be found to be cheaper for the contractor in the end. Many cases of permanent paralysis are due simply to lack of judgment in decompression; in such a case the contractors are forced to pay fees under the workmen's compensation laws during the rest of the workman's life, whereas had the man been cared for by a physician experienced in the treatment of compressed-air illness recovery might have been immediate. Paragraph *h* is designed to prevent ambulance surgeons from wasting time in transporting men suffering from compressed-air illness to hospitals when the medical lock furnishes the only adequate treatment for their condition.

8. ***Posted copies of the labor law.*** *Rule 1174.* Copies of such sections of the labor law as apply shall be printed in such languages as will be understood and furnished by the Industrial Commission to the person in charge and posted by him in a conspicuous place at the entrance of each work place.

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9. *Locks.* ***Rule 1178.*** Each bulkhead in tunnels of twelve feet or more in diameter or equivalent area shall have at least two locks in perfect working condition, one of which shall be used as a man lock.

The man lock shall be large enough so that those using it are not compelled to be in a cramped position, and shall not be less than five feet in height. The emergency lock shall be large enough to hold an entire heading shift.

All locks used for decompression shall be lighted by electricity and shall contain a pressure gage, a timepiece, a glass "bull's-eye" in each door or in each end, and shall also have facilities for heating.

Valves shall be so arranged that the locks can be operated both from within and from without.

10. *Records of decompression.* *Rule 1179.* Where air pressure reaches seventeen pounds, a record of all men working in the air chamber shall be kept by a man detailed for that purpose, who shall remain outside the lock near the entrance. This record shall show the period of stay in the air chamber of each person and the time taken for decompression.

11. *Compressor plants.* *Rule 1186.* A good and sufficient air plant for the compression of air shall be provided not only to meet ordinary conditions, but emergencies, and to provide margin for repairs at all times. This plant shall be capable of furnishing to each working chamber a sufficient air supply for all pressures to enable work to be done as nearly as possible in the dry.

Duplicate air feed pipes shall be installed on all caissons.

Every effort shall be made by the best available means to keep the temperature in the working chamber below 100 degrees Fahrenheit.

FORMS FOR RECORDS.

The following regular forms have been adopted in New York, so that the records of the cases and of the examination of men shall be uniform:

FORM FOR REPORTING COMPRESSED-AIR ILLNESS.

Location______________________ Date______________________
Name______________________ Check no.______________________
Address____
Country of birth______________________ Color______________________
Age______________Single, Married, Widower, or Divorced______________
Present occupation____
How long has he worked in compressed air______________________
Date employed by present employer______________________
Present employer____
Present attack____
Air pressure______________________________lbs.
Time of shifts:
From______________________ to______________________
From______________________ to______________________
Time of decompression:
First lock______________________________minutes.
Second lock______________________________ minutes.
Character of illness____
____
Onset of illness; Date______________192__Time____________A. M./P. M.

How long after leaving lock did symptoms appear?____________

Treatment____________

Medical-lock decompression:

____________lbs. to____________lbs. in________minutes.

____________lbs. to____________lbs. in________minutes.

____________lbs. to____________lbs. in________minutes.

Relieved: Yes.

No.

Signed: ____________

FORM TO BE USED BY PHYSICIANS.

[Medical examiner's report of workers under compressed air.]

No____________ Location____________

Name____________ Residence____________

Age________ Nationality________ Color________

Single_____ Married_____ Widower_____ Children_____ How many_____

Compressed air experience:

When________ Where________ Pressure________

Compressed air illness________ When________ Character________

Previous illness________ When________ Character________

State fully habits with regard to the use of—

(*a*) Alcohol____________

(*b*) Tobacco____________

When last attended by a physician and for what cause____________

____

____

Signature of applicant.

Height________ Weight________ Sight________ Hearing________

Pulse________ Character____________

Is the character of the heart action free and clear?____________

Are its sounds and rhythm regular and normal?____________

Are there any indications of disease of this organ or of the blood vessels?______

Circumference of chest____________

(*a*) Forced expiration________ (*b*) Forced inspiration________

____

Number of respirations____________

Is the respiratory murmur clear and distinct?____________

General appearance and carriage____________

Blood pressure________ (*a*) Systolic________ (*b*) Diastolic________

Are the muscular and nervous systems apparently in a healthy state?________

Is there any swelling of the face, abdomen, or lower extremities?________

Has he a hernia?____________

What is the specific gravity of his urine?____________

(*a*) Albumen ____________

(*b*) Sugar ____________

Full or half shift.

ACCEPTED. REJECTED. REMARKS____________

Date____________, 192__. ____________M. D.

Medical examiner.

Reexamined________, 192__. Remarks____________M. D.

Reexamined________, 192__. Remarks____________M. D.

Reexamined________, 192__. Remarks____________M. D.

Reexamined________, 192__. Remarks____________M. D.

NEW JERSEY.

The law of New Jersey (acts of 1914, chap. 121) relating to work in compressed air is as follows:

DEFINITIONS.

SECTION 1. (1) The term "pressure," when used in this act, means gage pressure in pounds per square inch.

(2) The term "employer," when used in this act, includes partnerships and corporations.

PROVISIONS FOR HEALTH AND SAFETY.

SEC. 2. Every tunnel, caisson, compartment, or place to which this act applies shall be so constructed, equipped, arranged, operated, and conducted as to provide such protection to the lives, health, and safety of all persons employed therein as the nature of the employment will reasonably permit.

REQUIREMENTS.

SEC. 3. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall:

(1) Provide and install gages in each tunnel for showing the air pressure to which the persons so employed therein are subjected. Such gages shall be accessible at all times during working hours to all employees in the tunnels.

(2) Provide and attach gages to each caisson for showing the air pressure to which the persons so employed therein are subjected, and employ a competent person, who may be the lock tender, to take charge of such gages and of the instruments required under subdivision three of this section. The person so employed shall not be permitted to work more than eight hours in any twenty-four hours.

(3) Provide and attach an air gage and a timepiece to each air lock. Such gage and timepiece shall be accessible to the lock tender at all times.

(4) Keep at least two air pipes or lines connected with each tunnel, caisson, compartment, or place in which persons are so employed.

(5) Provide a suitable iron ladder for the entire length of every shaft used in connection with such work.

(6) Keep every passageway used in connection with such work clear and properly lighted.

(7) Provide sufficient electric lights for all lighting purposes, and provide a wire for lighting the shaft, which wire shall be separated from the wire used for lighting the place where the employees are at work in compressed air; all electric wires shall be properly insulated.

(8) Provide, for the use of all persons so employed, dressing rooms which shall be kept open and accessible during working hours and during the intervals between working periods, and also a separate room for drying clothes. The dressing rooms shall contain benches and individual lockers, shower baths with hot and cold water, and sanitary water-closets, and shall be kept properly heated, lighted, and ventilated.

HOSPITAL LOCK.

(9) If the maximum air pressure in such work exceeds seventeen pounds, provide and maintain at least one double-compartment hospital lock. Such lock shall be at least six feet high, inside measurement, and be suitably floored; it

shall be equipped with inside and outside air gages and timepieces, and a telephone with proper connections, and shall contain benches and proper surgical and medical equipment; it shall be properly heated, lighted, and ventilated.

POSITION OF CAISSON.

SEC. 4. No caisson in which persons are employed in compressed air shall, while work is in progress therein, be suspended or hung so that the bottom of the excavation is more than four feet below the cutting edge of the caisson.

DAILY INSPECTION.

SEC. 5. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall cause all engines, boilers, steam pipes, steam gages, drills, caissons, air pipes, air gages, air locks, dynamos, electric wiring, signal apparatus, brakes, buckets, hoists, cables, chains, ropes, ladders, ways, tracks, sides, roofs, timbers, supports, and all other equipment, apparatus, or appliances used in connection with such work to be inspected at least once every working day by a competent person, especially designated for that purpose, and if any defect in such equipment, apparatus, or appliances is found a report thereof in writing shall forthwith be made by the inspector to the employer, and the defect shall be immediately repaired.

SEC. 6. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall:

PHYSICIANS.

(1) Employ one or more licensed physicians as medical officers, who shall be present to render medical assistance at all necessary times at the place where such work is in progress and who shall perform such other duties as are imposed on them by this act.

NURSES.

(2) If the maximum air pressure in such work exceeds seventeen pounds, employ one or more registered nurses, or one or more competent persons, which persons shall be selected by the medical officer and be certified by him to be competent, by actual experience, to handle cases of compressed-air illness. The nurses or persons so employed shall have charge of the hospital lock provided for in this act, and may also have other duties of a clerical nature, exclusive of timekeeping, such as will not require their presence elsewhere than at the hospital lock and such as they may leave at any time their service at the lock 's necessary.

INTEMPERATE EMPLOYEES.

SEC. 7. No persons known to be addicted to the excessive use of intoxicants shall be employed or permitted to work in compressed air.

PHYSICAL EXAMINATIONS.

SEC. 8. (1) No person shall be employed or permitted to work in compressed air until he has been examined by the medical officer and found to be physically qualified therefor.

(2) No person who has not previously worked in compressed air shall during the first twenty-four hours of his employment be permitted to work therein longer than one working period, as provided in section ten, and he shall not be permitted to resume such work, if the air pressure exceeds fifteen pounds, until he has been reexamined by the medical officer and found to be physically qualified therefor.

(3) No person who is employed in compressed air, but who has been absent therefrom for ten or more consecutive days for any cause, shall be permitted to resume such work until he has been reexamined by the medical officer and found to be physically qualified therefor.

(4) No person who has been employed regularly in compressed air for three months shall be permitted to continue such work until he has been reexamined by the medical officer and found to be physically qualified therefor.

RECORDS.

SEC. 9. The medical officer shall keep a record of all physical examinations made in accord with section eight, which record shall be kept at the place where the work is in progress and shall contain the name, age, address, and full description of each person examined, the date on which each examination was made, and the physical condition on that date of the person examined, and the total time such person has worked in compressed air, including time in previous employments. The employer shall also be responsible for the observance of this section.

HOURS OF SERVICE.

SEC. 10. When the air pressure in any tunnel, caisson, compartment, or place in which persons are employed exceeds normal, but does not exceed fifty pounds, the maximum number of hours which in any twenty-four hours a person may be employed or permitted to work or remain therein shall be as hereafter stated. In every case the maximum number of hours shall be divided into two working periods of equal length, and the minimum time interval which shall elapse between such working periods shall be as hereafter stated:

When the air pressure—	Number of hours in 24.	Interval between working periods.
Exceeds normal, but does not exceed 21 pounds	8	30 minutes.
Exceeds 21, but does not exceed 30 pounds	6	1 hour.
Exceeds 30, but does not exceed 35 pounds	4	2 hours.
Exceeds 35, but does not exceed 40 pounds	3	3 hours.
Exceeds 40, but does not exceed 45 pounds	2	4 hours.
Exceeds 45, but does not exceed 50 pounds	1½	5 hours.

Except in cases of emergency no person shall be permitted to work or remain in any tunnel, caisson, compartment, or place where air pressure exceeds 50 pounds.

DECOMPRESSION IN LOCKS.

SEC. 11. No person shall be permitted to pass from any tunnel, caisson, compartment, or place where he has been employed in compressed air to atmosphere or normal pressure without passing through an intermediate lock or state of decompression. When the employee is passing from a tunnel to atmosphere of normal pressure, the rate of decompression shall be three pounds every two minutes except when the air pressure in the tunnel exceeds 36 pounds, in which case the rate of decompression shall be one pound every minute. When the employee is passing from a caisson, compartment, or place to atmosphere of normal pressure, the time of decompression shall be as follows:

When the pressure in a caison, compartment, or place—

	Time of decompression, minutes.
Exceeds normal, but does not exceed 10 pounds	1
Exceeds 10, but does not exceed 15 pounds	2
Exceeds 15, but does not exceed 20 pounds	5
Exceeds 20, but does not exceed 25 pounds	10
Exceeds 25, but does not exceed 30 pounds	12
Exceeds 30, but does not exceed 36 pounds	15
Exceeds 36, but does not exceed 40 pounds	20
Exceeds 40, but does not exceed 50 pounds	25

ENFORCEMENT.

SEC. 12. The Commissioner of Labor shall enforce this act. The commissioner, the assistant commissioner, and the inspectors of the Department of Labor shall inspect every place of employment included in this act, and for that purpose may enter any such place.

VIOLATIONS.

SEC. 13. Every person who, either personally or through any agent, violates or fails to comply with any provision of this act is liable to a civil penalty of fifty dollars for the first offense, one hundred dollars for the second offense, and three hundred dollars for the third and each subsequent offense. Such penalties shall be recovered in an action of debt by and in the name of the Commissioner of Labor of the State of New Jersey, and shall be paid to the Commissioner of Labor, who shall pay the same to the Treasurer of the State of New Jersey.

Approved, April 7, 1914.

LAW OF PENNSYLVANIA.

The act of July 19, 1917, of the Pennsylvania Legislature contains the following provisions relative to work in compressed air:

DEFINITIONS.

SECTION 1. The term "pressure," when used in this act, means "gage pressure in pounds per square inch."

The term "employer," when used in this act, includes individuals, copartnerships, associations, and corporations.

PROVISIONS FOR SAFETY.

SEC. 2. Every tunnel, caisson, compartment, or place to which this act applies shall be so constructed, equipped, arranged, operated, and conducted as to provide such protection to the lives, health, and safety of all persons employed therein as the nature of the employment will reasonably permit.

DUTIES OF EMPLOYERS.

SEC. 3. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall:

(1) Provide and install gages in each tunnel, for showing the air pressure to which the persons so employed therein are subjected. Such gages shall be accessible at all times during working hours to all employees in the tunnels.

(2) Provide and attach gages to each caisson, for showing the air pressure to which the persons so employed therein are subjected, and employ a competent person, who may be the lock tender, to take charge of such gages and of the instruments required under subdivision three of this section. The person so employed shall not be permitted to work more than eight hours in any twenty-four hours.

(3) Provide and attach an air gage and a timepiece to each airlock. Such gage and timepiece shall be accessible to the lock tender at all times.

(4) Keep at least two air pipes or lines connected with each tunnel, caisson, compartment, or place in which persons are so employed.

(5) Provide a suitable iron ladder for the entire length of every shaft used in connection with such work.

(6) Keep every passageway used in connection with such work clear and properly lighted.

(7) Provide sufficient electric lights for all lighting purposes, and provide a wire for lighting the shaft, which wire shall be separated from the wire used for lighting the place where the employees are at work in compressed air; all electric wires shall be properly insulated.

(8) Provide for the use of all persons so employed dressing rooms, which shall be kept open and accessible during working hours and during intervals between working periods, and also a separate room for drying clothes. The dressing rooms shall contain benches and individual lockers, shower baths (with hot and cold water), and sanitary water-closets, and shall be kept properly heated, lighted, and ventilated.

(9) If the maximum air pressure in such work exceeds seventeen pounds, provide and maintain at least one double-compartment hospital lock. Such lock shall be at least six feet high, inside measurement, and be suitably floored. It shall be equipped with inside and outside air gages and timepieces and a telephone with proper connections and shall contain benches and proper surgical and medical equipment. It shall be properly heated, lighted, and ventilated.

POSITION OF CAISSON.

SEC. 4. No caisson in which persons are employed in compressed air shall, while work is in progress therein, be suspended or hung so that the bottom of the excavation is more than four feet below the cutting edge of the caisson.

INSPECTION DAILY.

SEC. 5. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall cause all engines, boilers, steam pipes, steam gages, drills, caissons, air pipes, air gages,, airlocks, dynamos, electric wiring, signal apparatus, brakes, buckets, hoists, cables, chains, ropes, ladders, ways, tracks, sides, roofs, timbers, supports, and all other equipment, apparatus, and appliances used in connection with such work to be inspected at least once every working day by a competent person especially designated for that purpose; and if any defect in such equipment, apparatus, or appliances is found, a report thereof in writing shall forthwith be made by the inspector to the employer, and the defect shall be immediately repaired.

PHYSICIANS AND NURSES.

SEC. 6. Every employer carrying on any work in the prosecution of which persons are employed in compressed air shall:

(1) Employ one or more licensed physicians as medical officers, who shall be present to render medical assistance at all necessary times at the place where such work is in progress, and who shall perform such other duties as are imposed on them by this act.

(2) If the maximum air pressure in such work exceeds seventeen pounds, employ one or more registered nurses, or one or more competent persons, which persons shall be selected by the medical officer and be certified by him to be competent by actual experience to handle cases of compressed-air illness. The nurses or persons so employed shall have charge of the hospital lock provided for in this act, and may also have other duties of a clerical nature, exclusive of timekeeping, such as will not require their presence elsewhere than at the hospital lock and such as they may leave at any time their service at the lock is necessary.

USE OF INTOXICANTS.

SEC. 7. No persons known to be addicted to the excessive use of intoxicants shall be employed or permitted to work in compressed air.

PHYSICAL EXAMINATIONS.

SEC. 8. (1) No person shall be employed or permitted to work in compressed air until he has been examined by the medical officer and found to be physically qualified therefor.

(2) No person who has not previously worked in compressed air shall, during the first twenty-four hours of his employment, be permitted to work therein longer than one working period, as provided in section ten, and he shall not be permitted to resume such work, if the air pressure exceeds fifteen pounds, until he has been reexamined by the medical officer and found to be physically qualified therefor.

(3) No person who is employed in compressed air, but who has been absent therefrom for ten or more consecutive days for any cause, shall be permitted to resume such work until he has been reexamined by the medical officer and found to be physically qualified therefor.

(4) No person who has been employed regularly in compressed air for three months shall be permitted to continue such work until he has been reexamined by the medical officer and found to be physically qualified therefor.

RECORDS.

SEC. 9. The medical officer shall keep a record of all physical examinations made in accord with section eight, which record shall be kept at the place where the work is in progress, and shall contain the name, age, address, and full description of each person examined, the date on which each examination was made and the physical condition on that date of the person examined, and the total time such person has worked in compressed air, including time in previous employments. The employer shall also be responsible for the observance of this section.

WORKING TIME.

SEC. 10. When the air pressure in any tunnel, caisson, compartment, or place in which persons are employed exceeds normal, but does not exceed fifty pounds, the maximum number of hours which, in any twenty-four hours, a person may be employed or permitted to work or remain therein shall be as hereinafter stated. In every case the maximum number of hours shall be divided into two working periods of equal length, and the minimum time interval which shall elapse between such working periods shall be as hereafter stated.

When the air pressure exceeds normal but does not exceed twenty-one pounds, number of hours in twenty-four, eight; interval between working periods, thirty minutes.

When the air pressure exceeds twenty-one but does not exceed thirty pounds, number of hours in twenty-four, six; interval between working periods, one hour.

When the air pressure exceeds thirty but does not exceed thirty-five pounds, number of hours in twenty-four, four; interval between working periods, two hours.

When the air pressure exceeds thirty-five but does not exceed forty pounds, number of hours in twenty-four, three; interval between working periods, three hours.

When the air pressure exceeds forty but does not exceed forty-five pounds, number of hours in twenty-four, two; interval between working periods, four hours.

When the air pressure exceeds forty-five but does not exceed fifty pounds, number of hours in twenty-four, one and one-half; interval between working periods, five hours.

Except in cases of emergency, no person shall be employed or permitted to work or remain in any tunnel, caisson, compartment, or place where air pressure exceeds fifty pounds.

DECOMPRESSION.

SEC. 11. No person shall be permitted to pass from any tunnel, caisson, compartment, or place where he has been employed in compressed air to atmosphere or (of) normal pressure, without passing through an intermediate lock or stage of decompression. When the employee is passing from a tunnel to atmosphere of normal pressure the rate of decompression shall be three pounds every two minutes, except when the air pressure in the tunnel exceeds thirty-six pounds, in which case the rate of decompression shall be one pound every minute. When the employee is passing from a caisson, compartment, or place to atmosphere of normal pressure the time of decompression shall be as follows:

When the pressure in a caisson, compartment, or place exceeds normal but does not exceed ten pounds, time of decompression one minute.

When the pressure in a caisson, compartment, or place exceeds ten but does not exceed fifteen pounds, time of decompression two minutes.

When the pressure in a caisson, compartment, or place exceeds fifteen but does not exceed twenty pounds, time of decompression five minutes.

When the pressure in a caisson, compartment, or place exceeds twenty pounds but does not exceed twenty-five pounds, time of decompression ten minutes.

When the pressure in a caisson, compartment, or place exceeds twenty-five pounds but does not exceed thirty pounds, time of decompression twelve minutes.

When the pressure in a caisson, compartment, or place exceeds thirty but does not exceed thirty-six pounds, time of decompression fifteen minutes.

When the pressure in a caisson, compartment, or place exceeds thirty-six but does not exceed forty pounds, time of decompression twenty minutes.

When the pressure in a caisson, compartment, or place exceeds forty but does not exceed fifty pounds, time of decompression twenty-five minutes.

ENFORCEMENT.

SEC. 12. The Commissioner of Labor and Industry shall enforce this act. In enforcing this act any employee or agent of the Department of Labor and Industry, specially authorized in writing, may at any time enter any place of employment covered by this act for purposes of inspection. It shall be unlawful to hinder or prevent such employee or agent in the performance of his duties under this act.

VIOLATIONS.

SEC. 13. Every person who, directly or indirectly, violates or fails to comply with any provisions of this act is liable to a penalty of $50 for the first offense, $100 for the second offense, and $300 for the third and each subsequent offense. Such penalties shall be recovered as debts of like amount are recoverable, in action to be brought for the use of the Commonwealth by or under the direction of the Commissioner of Labor and Industry.

Approved the 19th day of July, 1917.

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PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

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BULLETIN 87. Houses for mining towns, by J. H. White. 1914. 64 pp., 8 pls., 9 figs.

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BULLETIN 140. Occupational hazards and accident prevention at blast-furnace plants, based on records of accidents at blast furnaces in Pennsylvania in 1915, by F. M. Willcox. 1917. 155 pp., 16 pls.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosives, by G. A. Burrell. 1912. 15 pp.

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TECHNICAL PAPER 260. Miners' consumption in the mines of Butte, Mont., by Daniel Harrington and A. J. Lanza. 1921. 19 pp.

TECHNICAL PAPER 261. Oil-camp sanitation, by C. P. Bowie. 1921. 32 pp., 3 pls., 4 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

TECHNICAL PAPER 33. Sanitation at mining villages in the Birmingham district, Ala., by D. E. Woodbridge. 1913. 27 pp., 1 pl., 9 figs. 5 cents.

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